BULLETINS Nos. 369 AND 370. DECEMBER, 1913.

# New York Agricultural Experiment Station.

GENEVA, N. Y.

## No. 369. THE INJURIOUS EFFECT OF FORMALDEHYDE GAS ON POTATO TUBERS.

F. C. STEWART AND W. O. GLOYER.

## No. 370. THE EFFICIENCY OF FORMALDEHYDE IN THE TREATMENT OF SEED POTATOES FOR RHIZOCTONIA.

W. O. GLOYER.

PUBLISHED BY THE DEPARTMENT OF AGRICULTURE.

c. 18 · VI · 14 ·
P. L.

## BOARD OF CONTROL.

GOVERNOR MARTIN H. GLYNN, Albany.
COMMISSIONER CALVIN J. HUSON, Albany.
THOMAS B. WILSON, Hall.
BURT E. SMALLEY, Interlaken.
G. HYDE CLARKE, Cooperstown.
HENRY C. HARPENDING, Dundee.
EUGENE M. ANDREWS, Union.
C. WILLARD RICE, Geneva.
ADRIAN TUTTLE, Watkins.

## OFFICERS OF THE BOARD.

BURT E. SMALLEY, *President*

WILLIAM O'HANLON, *Secretary and Treasurer.*

## STATION STAFF.

WHITMAN H. JORDAN, Sc.D., LL.D., *Director.*

GEORGE W. CHURCHILL, *Agriculturist and Superintendent of Labor.*
WILLIAM P. WHEELER, *First Assistant (Animal Industry).*
ROBERT S. BREED, PH.D., *Bacteriologist.*
HAROLD J. CONN, PH.D., *Associate Bacteriologist.*
GODFREY L. A. RUEHLE, M.S.,
JAMES D. BREW, B.S., *Assistant Bacteriologists.*
FRED C. STEWART, M.S., *Botanist.*
WALTER O. GLOYER, A.M.,
**FOREST M. BLODGETT, B.S.A., *Associate Botanists.*
MANCEL T. MUNN, B.S., *Assistant Botanist.*
LUCIUS L. VAN SLYKE, PH.D., *Chemist.*
ALFRED W. BOSWORTH, A.M.,
ERNEST L. BAKER, B.S.,
RUDOLPH J. ANDERSON, B.S., *Associate Chemists.*
ARTHUR W. CLARK, B.S.,
MORGAN P. SWEENEY, A.M.,
OTTO MCCREARY, B.S.,
ALFRED K. BURKE, B.S., *Assistant Chemists.*
GEORGE A. SMITH, *Dairy Expert.*
FRANK H. HALL, B.S., *Vice-Director; Editor and Librarian.*
PERCIVAL J. PARROTT, M.A., *Entomologist.*
WILLIAM J. SCHOENE, M.S.,
§FRED Z. HARTZELL, M.A., *Associate Entomologists.*
HAROLD E. HODGKISS, B.S.,
BENTLEY B. FULTON, B.A., *Assistant Entomologists.*
ULYSSES P. HEDRICK, Sc.D., *Horticulturist.*
ROY D. ANTHONY, M.S.A.,
§FRED E. GLADWIN, B.S., *Associate Horticulturists.*
GEORGE H. HOWE, B.S.A.,
CHARLES B. TUBERGEN, B.S., *Assistant Horticulturists.*
ORRIN M. TAYLOR, *Foreman in Horticulture.*
JOSEPH F. BARKER, M.S., *In Charge of Soil Investigations.*
RICHARD F. KEELER, A.B., *Assistant Chemist (Soils).*
REGINALD C. COLLISON, M.S., *Assistant Chemist (Soils and Horticulture).*
‡F. ATWOOD SIRRINE, M.S., *Special Agent.*
GERTRUDE S. MAYO, *Director's Secretary.*
FRANK E. NEWTON,
WILLARD F. PATCHIN,
LENA G. CURTIS,
AGNES E. RYAN,
ESTHER F. HAWKINS, *Clerks and Stenographers.*
ADIN H. HORTON, *Computer and Mailing Clerk.*

Address all correspondence, not to individual members of the staff, but to the NEW YORK AGRICULTURAL EXPERIMENT STATION, GENEVA, N. Y.

The Bulletins published by the Station will be sent free to any farmer applying for them.

---

‡ Riverhead, N. Y. § Connected with Grape Culture Investigations. ** Connected with Hop Culture Investigations; absent on leave.

BULLETIN No. 369.

# THE INJURIOUS EFFECT OF FORMALDEHYDE GAS ON POTATO TUBERS.

F. C. STEWART AND W. O. GLOYER.

## SUMMARY.

In treating a quantity of seed potatoes with formaldehyde gas for scab at the Station in the spring of 1912, many of them were so severely injured that they were unfit for seed. The injury took the form of sunken brown spots surrounding the lenticels and eyes. The gas was generated by the permanganate method, using the standard formula of 3 pints of formaldehyde solution and 23 ounces of potassium permanganate to each 1000 cubic feet of space. An investigation into the cause of the injury placed the blame chiefly upon the small quantity (1.5 lbs.) of potatoes per cubic foot of space in the fumigation chamber. The high relative humidity of the air and the sprouted condition of the potatoes were important accessories. By the property of adsorption the potatoes seize and hold the formaldehyde gas upon their surface. If there are but few potatoes they adsorb so much gas that the tissue is injured; but when the gas is distributed over a large quantity of potatoes it does not gather at any point in sufficient quantity to cause injury. In our experiments various degrees of lenticel spotting occurred with all quantities up to 12 lbs. per cubic foot, but no eye injury appeared when 5 lbs. or more per cubic foot were used. The effect of lenticel spotting on germination and growth have not been fully determined, but it is believed that there may be considerable lenticel spotting without material injury to the tubers for seed purposes. The gas treatment is to be recommended only in cases in which the liquid treatment is impracticable. With the gas treatment it is evident that in order to secure uniform results the quantity of the chemicals must be varied according to the quantity of potatoes per cubic foot of space, but further experiments are required to determine just how it should be done. At present, the only formula which can be recommended as being both safe and efficient for scab is that of 3 pints of formaldehyde and 23 ounces of permanganate to 167 bushels of potatoes in 1000 cubic feet of space.

Similar spotting of potato tubers results from exposure to the fumes of ammonia, bromine or ether, and from dipping or soaking in strong solutions of corrosive sublimate and formaldehyde. However, in the use of formaldehyde solution the quantity of potatoes treated has no appreciable influence on the degree of the injury. The same solution may be used at least ten times without loss of strength.

Rome, and some other varieties of apples, when injured by formaldehyde gas show, chiefly, lenticel spotting, while on Baldwin the injury usually appears as a browning of the skin resembling scald.

## ORIGIN AND DEVELOPMENT OF THE FORMALDEHYDE GAS TREATMENT.

The germicidal properties of formaldehyde solution were discovered by Loew [1] in 1888. During the next decade it came into wide use as a disinfectant and antiseptic.[2] Its use on seed potatoes as a preventive of scab (*Oöspora scabies* Thax.) originated with Dr. Arthur [3] of the Indiana Experiment Station in 1897. The method of treatment which he recommended is widely used and everywhere recognized as the standard. Simultaneously with the rise of formaldehyde solution as a disinfectant there came the use of formaldehyde gas for similar purposes. Being non-poisonous and harmless to metals and fabrics it soon became popular for the disinfection of rooms in which cases of contagious disease had occurred.[4] Several methods of generating the gas were employed. In 1904, the discovery of an improved method, called the formalin-permanganate method, was announced by Evans and Russell.[5] This consists in pouring a solution of formaldehyde over crystals of potassium permanganate. In the resulting chemical reaction a large amount of formaldehyde gas is liberated in the course of a few minutes. The chief merits

[1] Loew, O. Physiologische Notizen über Formaldehyd. Ber. Gesell. Morph. u. Phys. zu München, 1888.

[2] For the literature of this period see the bibliography appended to Arthur's paper in Ind. Sta. Bul. 65.

[3] Arthur, J. C. Formalin for prevention of potato scab. Ind. Sta. Bul. 65. 1897.

[4] The literature of formaldehyde disinfection prior to 1901 has been collected by Reischauer (*Hyg. Rundschau* 11: 636).

[5] Evans, H. D. and Russell, J. P. Formaldehyde disinfection. Me. State Bd. of Health Rpt. 13. 1904. Reprint.

of the method are three: (1) Simplicity; (2) freedom from danger of fire; and (3) the rapidity with which the gas is liberated.

From 1900 to 1905 Jones and Morse,[6] at the Vermont Experiment Station, experimented with the disinfection of seed potatoes by means of formaldehyde gas. In their early experiments the gas was generated by evaporating formaldehyde solution over a flame, but in 1905 they used the (then) new formalin-permanganate method with promising results. In Bulletin No. 141 of the Maine Station, published in March, 1907, Morse recommends the following treatment as applicable where a large quantity of seed potatoes is to be treated: "Place seed potatoes in bushel crates or shallow slat-work bins in a tight room. For each 1000 cubic feet of space spread 23 ounces of potassium permanganate evenly over the bottom of a large, flaring pan or pail placed in the middle of the room. Pour over this three pints of formalin. Close room at once and do not open for 24 to 48 hours."

In a later bulletin Morse[7] reports an experiment in which the above treatment was successfully applied on a commercial scale. He also relates the experience of a man who injured several barrels of tubers severely by placing the generator directly underneath and only a few inches below a large slat-work bin containing the potatoes to be treated. Morse obtained similar results experimentally. This led him to advise that "no potatoes should be placed directly above the generator." In the same place he writes as follows concerning the danger of injury:[8] "Five years of experience in treating potatoes with formaldehyde gas generated in various ways indicate that, if properly handled, the gas from 3 pints of 40 per ct. formaldehyde may be safely used to the 1000 cubic feet of space. In fact over 3 quarts to the 1000 cubic feet have been used repeatedly without injuring the germinating qualities of the tubers in the least."

Two years later the same writer again published directions for the gas treatment.[9] This time it was stated that "the disinfection with formaldehyde gas should be done before the sprouts begin to start on the seed tubers." The safety of the treatment, if made according to directions, was reiterated.

[6] Vt. Sta. Rpt. 13:281; 14:232; 15:227; 16:166; 17:397; 18:287.
[7] Morse, W. J. Potato diseases in 1907. Me. Sta. Bul. 149. 1907.
[8] *Loc. cit.* p. 314.
[9] Morse, W. J. Blackleg: a bacterial disease of the Irish potato. Me. Sta. Bul. 174. 1909.

## A PERPLEXING CASE OF INJURY.

In the spring of 1912 the writers undertook, for the first time, the disinfection of a quantity of seed potatoes in the manner recommended by Morse. The room used was a cellar 31.4 x 13.3 x 8.4 feet with a content of 3508 cubic feet. The floor and walls were of cement. The ceiling was airtight and the two windows nearly so, but around the door there was some opportunity for leakage of gas. At the time of treatment the cellar contained 87 bushels of potatoes and four bushels of apples. The potatoes were in slatted bushel crates piled two and three deep and arranged so as to permit of the free circulation of the gas about them on all sides except the top and bottom. Three generators were used. Two were large tin dishpans and the third a bushel measure of galvanized iron. They were placed on the floor, at equal distances apart, through the center of the cellar.

Each of the two dishpans was charged with 23 ounces of potassium permanganate crystals and 3 pints of 40 per ct. formaldehyde solution, while the bushel measure contained 35 ounces of potassium permanganate and 4.5 pints of formaldehyde. The total weight of permanganate was 81 ounces and the total quantity of formaldehyde 10.5 pints. Thus the chemicals were used in almost exactly the quantity and proportions recommended by Morse. The crates of potatoes were so disposed that none were nearer than 2.5 feet to a generator and none farther away than about 8 feet. The floor of the cellar was wet and the walls and ceiling damp with drops of condensed moisture. The humidity is not known but it must have been high. The temperature was about 45 degrees Fahr. The generators were started and the door closed at 2:30 P. M., May 1. Twenty-six hours later the door was opened and left open. At 8:30 A. M. on May 3 (16 hours after opening the door) the gas was still so strong in the back part of the cellar that one could not stay there more than a few minutes at a time. Accordingly, the windows were opened and a circulation of air secured. It must be that practically all of the gas was removed within 48 hours of the time of starting the generators. It appears that the dishpans were too small or too shallow since some of the residue was found on the floor around them after the cellar was opened.

On May 7 the writers were much surprised to find that the treatment had resulted in serious injury to some of the tubers, particularly

those most exposed on the surface of the top crates. The injury appeared in the form of sunken brown spots of various shapes and all sizes from a mere speck to about one-half inch in diameter. Sometimes larger spots were formed by the coalescence of two or more small spots. Many spots were circular with a lenticel at the center. Frequently, the eyes were surrounded by circular sunken areas of brown dead tissue. On many tubers as much as one-half of the total surface area was covered by the spots. Although the spots, particularly the larger ones, were conspicuously sunken, the layer of dead, brown tissue lining the depression was usually only one or two millimeters in thickness. It was rarely more than 3 millimeters thick. In one of the top crates containing 213 tubers 56 were so much injured as to be unfit for seed. In another top crate 67 per ct. of the tubers were more or less spotted while in the crate just beneath only 12 per ct. were spotted. The tubers in the entire 40 top crates were carefully sorted and 10 bushels, or 25 per ct., which showed more or less eye injury were rejected as unfit for seed. Apparently, the tubers in the lower crates were not sufficiently injured to materially affect their germination. However, it should be stated that where these potatoes were planted a very poor stand was obtained. This, we believe, was due to unfavorable soil and weather conditions rather than to any weakness of the seed. Even the worst-affected tubers were only slightly injured for culinary purposes, yet their disfiguration would certainly have affected their salability. They showed no tendency to rot and the spots did not increase in size or depth.

It was decided to make an inquiry into the cause of the injury.

## METHODS OF INVESTIGATION.

The season was so far advanced when the investigation was begun that it was impossible to do much experimental work in the spring of 1912. Three experiments were made during May and then the work was discontinued until January 30, 1913, when it was again taken up and pursued actively until May 26. Three additional experiments were made in the fall of 1913. The total number of fumigation experiments made was 89. The fumigation chamber was a wooden box of 21.56 cubic feet capacity. Its inside dimensions were 34.5 x 36 x 30 inches. It was constructed of well-seasoned matched lumber

and painted inside. On one side there was a hinged door 17 x 23 inches. In the first 30 experiments some leakage of gas occurred around the door. Then the fittings of the door were tightened so that in subsequent experiments (excepting No. 89) scarcely any odor of escaping gas could be detected. During 22 of the experiments (Nos. 31 to 37, 51 to 55 and 76 to 85) the box stood in the cement cellar where the original injury occurred; during 43 experiments (Nos. 1 to 30 and 38 to 50) it stood in the furnace room of a greenhouse; during 21 experiments (Nos. 56 to 73 and 87 to 89) it stood in an unheated barn where doors on opposite sides permitted a free circulation of the outside air; during Experiments 74 and 86 it stood in the open air; and in Experiment No. 75 under a shed open on one side. In the first eleven experiments the humidity is unknown and the temperature was not very accurately determined; but in experiments subsequent to No. 11, and excepting Nos. 87–89, both the humidity and the temperature were recorded by a Friez hygrothermograph [10] placed inside the box. The generator used was a pint tin cup with flaring sides. In the first four experiments the charge consisted of 14.06 grams of potassium permanganate and 30.6 cubic centimeters of formaldehyde solution. These quantities are equivalent to 23 ounces of permanganate and three pints of formaldehyde to 1000 cubic feet (Morse's formula), but as they were found somewhat difficult of exact measurement we used, instead, 14.25 grams $KMnO_4$ and 30 cubic centimeters $CH_2O$ in subsequent experiments. It will be observed that the ratio of $KMnO_4$ to $CH_2O$ is that recommended by Evans [11] and that the quantity of formaldehyde solution used was equal to 1391.4 cubic centimeters (a trifle less than three pints [12]) per 1000 cubic feet. In all but three of the experiments the time of exposure was 24 hours. The bulk of the potatoes were exposed in bushel crates, but in addition there was invariably a check of 10 to 40 test tubers spread upon the floor of the fumigation chamber. The test tubers were thoroughly washed in order that any injury to them might be readily detected. After treatment they were stored in a

[10] Kindly loaned by Dr. L. Knudson of the Department of Plant Physiology, New York State College of Agriculture.

[11] Evans, H. D. Disinfection by the formalin-permanganate method. Me. State Bd. of Health Rpt. 14:227–249. 1906.

[12] Three pints = 1419.45 cubic centimeters.

partially darkened room and kept under observation for at least two weeks. Unless otherwise stated all tubers were thoroughly dry at time of starting the experiment and of approximately the same temperature as the air of the room in which the experiment was made. The potassium permanganate was in the form of slender needle-shaped crystals. In all except the first three experiments the formaldehyde solution was taken from the same bulk. An analysis made by the Chemical Department of the Station showed that it contained 37.1 per ct. of formaldehyde.

## SEVERAL FACTORS INVOLVED.

Since the treatment was made strictly in accordance with the directions given by Morse it was evident that the injury was due to some factor not recognized and, probably, not encountered by him in his long experience with the treatment. Hence, the first step in the investigation was to determine in what respects the conditions of our case were unusual. It was noted: (1) That the temperature was low (45 degrees Fahr.); (2) that the relative humidity was very high (probably near the dew point); (3) that the quantity of potatoes treated was small in proportion to the space (1.5 lbs. per cubic foot); and (4) that the severely injured tubers were of the variety Sir Walter Raleigh while two bushels of another variety, Rural New Yorker No. 2, were only slightly injured.

Ultimately, it was discovered that the unknown chief factor was *the small quantity of potatoes* while the high relative humidity and sprouted condition of the tubers were important accessories. Besides these three principal factors there are, also, some minor ones which require consideration. The several factors entering into the problem will be discussed in turn.

### QUANTITY OF POTATOES.

In our original trial of the treatment (the one which brought about this investigation) the cellar contained about 1.5 lbs. of potatoes per cubic foot. As has already been stated, many of the tubers were severely injured. Our early experiments (Nos. 1–12) were all made with very small quantities of potatoes — less than one-half pound per cubic foot — and severe lenticel injury resulted in every case notwithstanding the temperature and humidity varied considerably in different experiments. It then occurred to us to try a much larger quantity. In Experiment No. 13 the fumigation

chamber contained 5.7 bushels or about 16 lbs. per cubic foot. When the door was opened, at the end of 24 hours, it was found that the formaldehyde gas had nearly all disappeared. Immediately after the door was opened one of the writers thrust his head into the box and held it there for over a minute without discomfort; whereas, in previous experiments the gas had been so strong as to be almost suffocating. The tubers were entirely free from injury. Three other experiments were made with 16 lbs. per cubic foot with the same result — the practical disappearance of the gas and no injury to the tubers. In other experiments varying quantities of potatoes were used in an attempt to determine the least quantity that could be treated with safety. Traces of lenticel injury occurred with all quantities up to 12 lbs. per cubic foot, but no eye injury appeared when five pounds or more per cubic foot were used. While the injury resulting from the treatment plainly bore an important relation to the quantity of potatoes per cubic foot, it did not decrease uniformly as the quantity of potatoes increased. In different experiments with the same quantity of potatoes varying degrees of injury resulted. The extent of this variation may be seen by an examination of Table I.

It having been determined that the exposure of a large quantity of potatoes caused the disappearance of the gas and prevented injury, the question arose as to the manner in which it is brought about. Does the gas enter into chemical combination with the substance of the potatoes or is it merely held on the surface of the tubers? When lesions appear there can be no doubt that some of the gas has combined with the contents of the cells and caused their death. It is known that formaldehyde may combine with protein bodies.[13] But when there are no lesions on the tubers the proof of chemical union is less evident. As regards the alternate proposition, chemists and physicists have long known that objects of many different kinds have the power of holding upon their surface considerable quantities of any gas surrounding them. This is known as

[13] Bliss, C. L., and Novy, F. G. Action of formaldehyde on enzymes and on certain proteids. *Jour. Exp. Med.* **4**:47–80. 1899.
Steinegger, R. Die Einwirkung des Formaldehyds auf die Eiweisskörper. *Land. Jahr. Schweiz* **19**:524–525. 1905.
Lepierre, C. Einwirkung des Formaldehyds auf die Eiweisskörper. Umwandlung der Peptone und Albuminosen in Primäre Eiweissstoffe. *Jour. Phar. Chim.* [6], **9**:449–451. 1899. Abstract in *Ztschr. Untersuch. Nahr. u. Genussmtl.* **2**:924. According to this author the action of formaldehyde on protein bodies consists in the condensation and withdrawal of water with the simultaneous occurrence of methyl groups in the protein molecule.

adsorption.[14] Several investigators of formaldehyde disinfection

[14] Patten and Waggaman (Absorption by soils. U. S. D. A. Bur. Soils Bul. No. 52. 1908) have given a résumé of the voluminous literature of absorption and adsorption, especially in its relation to soils. Their view of the nature of adsorption appears in the following statement (p. 11): "A special case of absorption has been termed *adsorption*, which may be defined as the existence of a difference in concentration or density of a film adjacent to a bounding solid and the concentration or density of the mass of the liquid or gas which bathes this solid. Whether this adsorbed film is in a liquid, solid, or gaseous state, or even loosely combined with the solid bounding medium, is not easily determined and has been the subject of much discussion. The change of state from solid to liquid and from liquid to vapor, is very gradual. All the recent physical researches, dealing even with hard, polished 'solid' surfaces, indicate a mobility of parts, an openness of structure, and a high power of retaining foreign material. But the ability of one body to hold another upon its surface is dependent upon the material of which each consists. So we are accustomed to say that adsorption depends upon the chemical constitution of the solid as well as of the substance adsorbed. Another way of stating the same idea is to attribute adsorption to a specific attraction between solid and adsorbed material."

The great adsorptive capacity of charcoal is well known and often utilized in various arts and industries. "Boxwood charcoal will in this way absorb ninety times its own volume of ammonia, fifty volumes of hydrogen sulphide, or nine volumes of oxygen. * * * The absorbed gases may be removed unchanged by heating the charcoal in a vacuum. The disappearance of these immense quantities of gas into small pieces of charcoal is described as *adsorption* and is caused by the adhesion of the gases to the very extensive internal surface which charcoal possesses. Solid and liquid bodies are also in many cases taken up by charcoal in a similar fashion. Thus, strychnine may be removed from an aqueous solution by agitation of the latter with charcoal. In the manufacture of whiskey, the fusel oil, which is extremely harmful is in many cases removed by filtration of the diluted spirit through charcoal, before rectification. Organic coloring matters, such as litmus and indigo, belong to the class of bodies thus extracted from solution by charcoal. In the refining of sugar the syrup is boiled with charcoal for the purpose of removing a brown resin, in order that the product may be perfectly white. It is, in part, upon this property that we rely, also, in the employment of charcoal filters. The organic materials dissolved in the drinking water undergo adsorption in the charcoal. In this connection, however, it must be remembered that the quantity which a given mass of charcoal may take up is limited, and that careful cleansing is required in order that the efficiency of the filter may be maintained." (Smith, Alexander. Introduction to general inorganic chemistry, p. 476, 1907.)

In discussing the relation of deleterious chemical agents to the growth of plants Duggar (Plant physiology with special reference to plant production, p. 440. 1911) says: "Solid particles such as pure sand, graphite, and filter paper, may reduce toxic action to a considerable extent. True and Oglevee [*Bot. Gaz.* 39:1–21. 1905] found that twice as much sand as solution may reduce the toxic action of Cu $So_4$ for *Lupinus albus* as much as thirty-two times. The method of reducing toxicity by solid particles is usually denoted adsorption. It is a phenomenon explained upon the hypothesis that many molecules (or ions) of the toxic substance are physically held by the surfaces of the particles of the inert material, and are, for the time, removed from the possibility of chemical action. Another explanation is that the solid substances offer obstacles to the free movement of the solvent particles. Possibly both views are important. Many of the so-called absorptive properties of soils both respecting fertilizers and deleterious agents are in reality adsorptive." On this phase of adsorption see, also, Jensen, G. H. Toxic limits and stimulation effects of some salts and poisons on wheat. *Bot. Gaz.* 43:11–44. 1907.

have observed that the formaldehyde gas is adsorbed to a great extent by objects in the disinfection chamber. It has been pointed out by Peerenboom,[15] Rubner and Peerenboom,[16] v. Brunn,[17] Jörgensen,[18] Walter and Schlossman,[19] and Werner[20] that the area of the surface exposed by the walls and objects in the room may affect, materially, the efficiency of the disinfection. However, it appears that little or no account is taken of this in practical disinfection in America.[21] In the formaldehyde gas treatment of seed potatoes it has been entirely ignored.

In order to determine whether the disappearance of the gas in the experiments described above was due to adsorption the following three experiments were made: A quantity of cobblestones (5.5 bu. = 786.5 lbs. = 1485 stones) approximately the size and shape of potatoes, and hence having approximately the same surface area as potatoes, were washed and dried, then placed in the fumigation box and treated with formaldehyde gas in the same manner as a similar quantity of potatoes had been treated in Experiments 13 and 16. The stones occupied six crates. Thirty cubic centimeters of formaldehyde solution and 14.25 grams of potassium permanganate were used. The fumigation chamber was kept closed 24 hours. The test objects were 20 potatoes just commencing to sprout. In the first stone experiment (No. 38) the initial humidity was 75 per ct. and the maximum 81 per ct.; the initial temperature

[15] Peerenboom. Zur Verhalten des Formaldehyds im geschlossenen Raum und zu seiner Desinfektionswirkung. *Hyg. Rundschau* **8**:776. 1898.

[16] Rubner u. Peerenboom. Beiträge zur Theorie und Praxis der Formaldelhyddesinfektion. *Hyg. Rundschau* **9**:266. 1899.

[17] v. Brunn, M. Formaldehyde desinfection durch Verdampfung verdünnten Formalins. *Ztschr. Hyg. u. Infectionskr.* **30**:216, 230. 1899.

[18] Jörgensen, A. Untersuchung über Formaldehyddesinfection nach der Breslauer Methode, speciell Desinfection von Uniformen betreffend. *Ztschr. Hyg. u. Infectionskr.* **45**:279. 1903. With bibliography of 72 numbers.

[19] Walter u. Schlossman. *München. Med. Wchnschr.* 1899. Cited by Jörgensen.

[20] Werner, G. Zur Kritik der Formaldehyddesinfektion. *Arch. Hyg.* **50**:361. 1904.

[21] Health officers in this country now quite generally employ formaldehyde gas, generated by the permanganate method, for the disinfection of rooms in which cases of contagious disease have occurred. The directions given usually call for a certain amount of formaldehyde solution and potassium permanganate per 1000 cubic feet of space without regard to the contents of the room.

Although McClintic's investigation (Pub. Health and Mar. Hosp. Ser. U. S. Hyg. Lab. Bul. 27. 1906) was made "with special reference to car sanitation" no account was taken of the area of surface exposed. Probably, the disappearance of the gas which McClintic observed in his car experiments and which he ascribed to leakage (p. 78) was in large part due to adsorption.

56 degrees Fahr. and the maximum 62 degrees Fahr. When the box was opened it was found that most of the gas had disappeared though there was still left enough to cause the eyes and throat to smart when one's head was held in the box. Apparently, there was a little more gas than in Experiment No. 13. Not a trace of injury of any kind appeared on the test tubers.

Between Experiments 38 and 39 the door of the fumigation chamber was left open for 2½ hours, but the stones were not removed. In the second stone experiment (No. 39) the initial humidity was 68 per ct. and the maximum 90 per ct.; the initial temperature, 59 degrees, the maximum 62 degrees. There were 20 test tubers, 10 of which had barely started to sprout while the other 10 had sprouts one-fourth inch long. The quantity of gas present when the door was opened seemed to be about the same as in the previous experiment. The only indication of injury was a slight browning of the tips and bases of some of the larger sprouts.

Between Experiments 39 and 40 the door of the fumigation chamber was left open 67 minutes for airing, but the stones were not removed.[22] In the third stone experiment (No. 40) the 20 test tubers bore sprouts one-fourth to one-half inch long. The initial humidity was 63 per ct. and the maximum 88 per ct.; the initial temperature 58 degrees and the maximum 61 degrees. The gas present at the close of the experiment appeared about the same as in the previous two experiments. Several of the larger sprouts were browned a little at the base and a few were killed, but the eyes sprouted again and the germination appeared normal. There was no lenticel injury.

These experiments with stones show the importance of adsorption in formaldehyde disinfection. It appears that stones have practically the same effect as potatoes in taking up the gas and preventing injury. As chemical union between the formaldehyde and the stones is impossible it must be that the gas was adsorbed on the surface of the stones. Hence, we conclude that when potatoes take up formaldehyde gas it is chiefly by adsorption.

That partly filling the fumigation chamber with stones or potatoes should have the effect of preventing injury to the test tubers appears

[22] Even though the stones were aired somewhat between experiments their capacity for adsorption must have been considerably reduced by the previous treatments. However, it was not shown in the effects on the test tubers.

paradoxical. By measuring the water displaced by a bushel of the stones it was computed that the 5.5 bushels of stones occupied 4.84 cubic feet of space. Hence, the introduction of the stones into the fumigation chamber reduced the space occupied by the gas from 21.56 cubic feet to 16.72 cubic feet. In the same manner it was determined that a bushel (60 lbs.) of potatoes occupies 1544 cubic inches of space.[23] Accordingly, in Experiments 13, 16, 55 and 86 in which the fumigation chamber contained 16 lbs. of potatoes per cubic foot, or a total quantity of 5.7 bushels, the potatoes occupied 5.09 cubic feet or nearly one-fourth of the total space content of the chamber. Were it not for the factor of adsorption this would result in increasing the concentration of the gas. As a matter of fact, the concentration of the gas was greatly *decreased.*

In our experiments we have been able to bring about injury or avoid it at will simply by varying the quantity of potatoes per cubic foot of space. When the quantity is small injury invariably results; when it is large there is no injury. This holds under all the conditions of humidity, temperature and germination ordinarily encountered in the treatment of seed potatoes. Hence, we conclude that our disaster in the spring of 1912 was due primarily to the small quantity of potatoes per cubic foot of cellar space.

That serious injury from the gas treatment has not been reported previously is probably due to the fact that small quantities of potatoes are rarely treated in large chambers owing to the large expense for chemicals. Dr. Morse informs us that in his experiments[24] at Houlton, Me., the disinfection chamber contained somewhat more than ten pounds per cubic foot. However, at other times considerably smaller quantities were treated in the same room and yet no injury was reported to him. Judging from our own experience it seems as if considerable lenticel spotting, at least, must have occurred in the experiments made by Jones and Morse [25] in 1904 and 1905. In a tight box containing 8.2 cubic feet they treated 30 lbs.

[23] The average of three tests in which the results varied from 1539.35 to 1550.33 cubic inches. The specific gravity of the tubers varied from 1.0711 to 1.0787, the average being 1.0744. Woods and Bartlett (Me. Sta. Bul. 57 : 151) found the specific gravity of potatoes to vary from 1.0604 to 1.1129. Watson, who made numerous determinations on several different varieties grown in different parts of the United States (Va. Sta. Buls. 55 and 56) gives 1.035 as the lowest and 1.103 as the highest specific gravity found.

[24] Reported in Maine Sta. Bul. 149:305.

[25] Vt. Sta. Rpts. 17:397–401 and 18:287–291.

of potatoes for 24 hours with the gas from 25 cubic centimeters of formaldehyde solution. That is, the quantity of potatoes was 3.7 lbs. per cubic foot and the quantity of formaldehyde solution more than twice the standard quantity. It may be that their failure to observe any injurious effect of the treatment was due to the tubers being planted before the injury manifested itself. If unsprouted tubers were used there may have been only lenticel spotting, without eye injury, and the germination may not have been materially affected.

In an attempt to duplicate their experiments we made Experiments 87–89. (See Table II.) Calculated for our fumigator, containing 21.56 cubic feet, the equivalent quantities of formaldehyde and potassium permanganate would be 65.75 cubic centimeters of the former and 24.65 grams of the latter. These quantities were used. Experiments 87 and 88 were made in the latter part of September with freshly-dug tubers. The varieties Irish Cobbler and Green Mountain were used in Experiment 87 and Sir Walter Raleigh and Gold Coin in Experiment 88. Experiment 89 was made in November with the varieties Sir Walter Raleigh and Rural New Yorker No. 2. Considerable leakage of gas occurred on Experiment 89. In all three of these experiments there was severe lenticel spotting but no eye injury.

The conditions under which the Vermont experiments were made appear to have been comparable, also, to those in our Experiment 78 (See Table II) in which the tubers showed considerable lenticel spotting and much eye injury.

TABLE I.— EFFECT OF FORMALDEHYDE GAS ON POTATO TUBERS: STANDARD TREATMENT.*

| Quantity of tubers. | Number of experiment. | Humidity. | | | Temperature. | | | Condition of test tubers before treatment. | Injury. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Initial. | Maximum. | Closing. | Initial. | Maximum. | Minimum. | | Lenticel spotting. | Eye injury. |
| *Tubers.* | | *Per ct.* | *Per ct.* | *Per ct.* | *Deg. F.* | *Deg. F.* | *Deg. F.* | | | |
| 12 | 1 | ..... | ..... | ..... | 67 | 69 | ..... | Sprouted | Much | Much. |
| 15 | 2 | ..... | ..... | ..... | 59 | 60 | ..... | Sprouted | Much | Much. |
| 34 | 3 | ..... | ..... | ..... | 64 | 72 | 47 | Sprouted | Much | Much. |
| 20 | 4 | ..... | ..... | ..... | 65 | 65 | 37 | Unsprouted | Much | None. |
| 29 | 5 | ..... | ..... | ..... | 50 | ..... | ..... | Unsprouted | Much | None. |
| 25 | 6 | ..... | ..... | ..... | 52 | 55 | 37 | 24 unsprouted | Considerable | None. |
| | | | | | | | | 1 slightly sprouted | Considerable | 2 eyes ruined. |
| 20 | 7 | ..... | ..... | ..... | 48 | 52 | 36 | Unsprouted | Much | None. |
| 20 | 8 | ..... | ..... | ..... | 51 | 55 | 40 | Unsprouted | Much | None. |
| 26 | 9 | ..... | ..... | ..... | 44 | 50 | 35 | Slightly sprouted | Much | Considerable. |
| 20 | 10 | 49 | ..... | ..... | 55 | 61 | 55 | Unsprouted | Much | None. |
| 35 | 11 | ..... | ..... | ..... | 56 | 61 | 43 | Unsprouted | Much | None. |
| 20 | 12 | 46 | 76 | 68 | 59 | 62 | 51 | Unsprouted | Much | None. |
| 20 | 14 | 66 | 86 | 71 | 63 | 66 | 55 | Unsprouted | Much | None. |
| 20 | 20 | 79 | 101 | 90 | 55 | 57 | 46 | Slightly sprouted | Much | Much. |
| 20 | 23 | 63 | 93 | 83 | 63 | 63 | 53 | Slightly sprouted | Much | Much. |
| 30 | 26 | 75 | 102 | 92 | 50 | 61 | 48 | 25 unsprouted | Much | None. |
| | | | | | | | | 5 sprouted | Considerable | Much. |
| 20 | 28 | 59 | 80 | 68 | 58 | 65 | 53 | 10 unsprouted | Much | Trace. |
| | | | | | | | | 10 sprouted, .12 in. | Much | Much. |
| 33 | 30 | 54 | 77 | 69 | 60 | 66 | 58 | 10 unsprouted | Much | None. |
| | | | | | | | | 10 barely started | Much | Much. |
| | | | | | | | | 13 sprouted, .12 in. | Much | Much. |

* As recommended by Morse. In first three experiments 30.6 cubic centimeters formaldehyde solution and 14.06 grams potassium permanganate to 21.56 cubic feet; in all others, 30 cubic centimeters formaldehyde and 14.25 grams permanganate to 21.56 cubic feet (= 3 pints formaldehyde and 23 ounces permanganate to 1,000 cubic feet). Time of exposure, 24 hours.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 31 | 83 | 87 | 75 | 41 | 43 | 40 | 10 unsprouted | Considerable | None. |
| | | | | | | | | 10 sprouted, .12 in | Considerable | Much. |
| 20 | 32 | 85 | 89 | 83 | 37 | 39 | 37 | Sprouted, .12 to .25 in | Considerable | Much. |
| 20 | 33 | 91 | 93 | 89 | 36 | 39 | 36 | 10 unsprouted | Much | None. |
| | | | | | | | | 10 sprouted, .12 to .25 in | Considerable | Considerable. |
| 20 | 35 | 90 | 92 | 90 | 42 | 45 | 42 | 10 unsprouted | Much | A little. |
| | | | | | | | | 10 sprouted, .12 to .25 in | Much | Much. |
| 20 | 36 | 90 | 92 | 90 | 43 | 46 | 41 | 10 unsprouted | Much | A little. |
| | | | | | | | | 10 sprouted, .12 to .25 in | Much | Much. |
| 20 | 37 | 88 | 89 | 85 | 41 | 43 | 40 | 10 unsprouted | Much | A little. |
| | | | | | | | | 10 sprouted, .5 in | Much | Much. |
| 40 | 44 | 71 | 101 | 94 | 58 | 65 | 54 | 20 sprouted, .25 in.; dry | Much | Much. |
| | | | | | | | | 20 sprouted, .25 in.; wet | Much | Much. |
| 36 | 59 | 45 | ..... | 77 | 50 | †58 | ..... | 10 varieties, barely started | Considerable | A little. |
| 36 | 65 | 48 | 88 | 79 | 63 | 66 | 57 | 10 varieties, sprouted, .25 in | Much | Considerable. |
| 23 | 72 | 71 | 96 | 83 | 53 | 61 | 53 | 11 barely started | Much | Much. |
| | | | | | | | | 12 sprouted, .5 in | Considerable | A little. |
| 33 | 73 | 50 | 89 | 82 | 68 | 71 | 60 | Sprouted | Much | Much. |
| *Lbs.** | | | | | | | | | | |
| 1.5 | 34 | 94 | 97 | 96 | 41 | 43 | 41 | Unsprouted | Much | None. |
| 1.5 | 50 | 64 | 85 | 78 | 55 | 63 | 55 | Part unsprouted | Considerable | None. |
| | | | | | | | | Part sprouted, .12 in | A little | Considerable. |
| 1.5 | 67 | 46 | 78 | 78 | 69 | 69 | 58 | Sprouted, .25 in | A little | Trace. |
| 1.5 | 76 | 79 | 91 | 86 | 54 | 56 | 53 | Sprouted, .06 to .12 in | Considerable | Much. |
| 1.5 | 80 | 66 | 82 | 70 | 50 | 51 | 49 | Sprouted, .12 to .25 in | Considerable | Much. |
| | | | | | | | | Sprouted, .75 in | A little | None. |
| 1.5 | 85 | 69 | 91 | 77 | 54 | 54 | 51 | Sprouted, .25 in | Considerable | Much. |
| 2 | 45 | 53 | 84 | 85 | 53 | 57 | 49 | Unsprouted | Considerable | None. |
| 2 | 48 | 71 | 86 | 83 | 69 | 70 | 60 | Part barely started | Much | None. |
| | | | | | | | | Part sprouted, .25 in | Much | Considerable. |
| 2 | 52 | 85 | 85 | 73 | 40 | 42 | 40 | Part barely started | A little | None. |
| | | | | | | | | Part sprouted, .12 in | A little | Trace. |
| 2 | 56 | 70 | 92 | 86 | 43 | 46 | 43 | Part barely started | Trace | None. |
| | | | | | | | | Part sprouted, .12 in | Trace. | Trace. |
| 2 | 79 | 62 | 81 | 74 | 49 | 50 | 48 | Sprouted, .12 to .25 in | Considerable | Much. |

*Number of pounds per cubic foot of space in fumigation chamber.

† Closing temperature. The temperature and humidity pointers became entangled soon after the experiment started and did not free themselves until near the close. Hence, only the initial and closing temperature and humidity are known.

TABLE I — *continued*

| Quantity of tubers. | Number of experiment. | Humidity. | | | Temperature. | | | Condition of test tubers before treatment. | Injury. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Initial. | Maximum. | Closing. | Initial. | Maximum. | Minimum. | | Lenticel spotting. | Eye injury. |
| *Lbs.** | | *Per ct.* | *Per ct.* | *Per ct.* | *Deg. F.* | *Deg. F.* | *Deg. F.* | | | |
| 2 | 83 | 89 | 94 | 90 | 50 | 51 | 49 | Sprouted, .25 in | Considerable | Much. |
| 3 | 43 | 54 | 84 | 78 | 54 | 60 | 54 | Barely started | Trace | None. |
| 3 | 46 | 55 | 80 | 80 | 55 | 62 | 55 | Part barely started | Considerable | None. |
| | | | | | | | | Part sprouted, .25 in | A little | Trace. |
| | | | | | | | | Part sprouted, .75 in | Trace | Trace. |
| 3 | 51 | 60 | 77 | 77 | 45 | 46 | 40 | Part barely sprouted | Trace | None. |
| | | | | | | | | Part sprouted, .12 to .25 in | Trace | Trace. |
| 3 | 57 | 77 | 89 | 85 | 46 | 50 | 46 | Part barely sprouted | Trace | None. |
| | | | | | | | | Part sprouted, .12 to .25 in | Trace | None. |
| 3 | 61 | 58 | 89 | 87 | 48 | 48 | 37 | Sprouted, .12 to .25 in | None | None. |
| 3 | 63 | 58 | 80 | 78 | 47 | 55 | 47 | Sprouted, .5 in | Trace | None. |
| 3 | 64 | 64 | 86 | 83 | 65 | 65 | 55 | Sprouted, .5 to .75 in | Trace | A little. |
| 3 | 66 | 51 | 80 | 78 | 69 | 69 | 61 | Sprouted, .75 to 1 in | A little | None. |
| 4 | 77 | 80 | 89 | 83 | 53 | 55 | 52 | Sprouted, .06 to .12 in | Considerable | Considerable. |
| 4 | 42 | 61 | 87 | 76 | 54 | 58 | 53 | Barely started | Considerable | None. |
| 4 | 47 | 66 | 77 | 76 | 62 | 68 | 62 | Barely started | A little | None. |
| 4 | 58 | 62 | 91 | 91 | 49 | 50 | 45 | Part barely started | None | None. |
| | | | | | | | | Part sprouted, .25 in | None | None. |
| 4 | 70 | 59 | 88 | 88 | 47 | 51 | 47 | Part barely started | A little | None. |
| | | | | | | | | Part sprouted, .5 to .75 in | None | None. |
| 4 | 84 | 90 | 96 | 91 | 50 | 52 | 50 | Sprouted, .25 in | Considerable | Much. |
| 5 | 41 | 60 | 90 | 89 | 54 | 57 | 54 | Barely started | A little | None. |
| 5 | 49 | 51 | 82 | 82 | 58 | 58 | 54 | Part barely started | A little | None. |
| | | | | | | | | Part sprouted, .12 in | A little | None. |
| 6 | 29 | 40 | 74 | 73 | 64 | 67 | 57 | Unsprouted | A little | None. |

* Number of pounds per cubic foot of space in fumigation chamber.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 27 | 62 | 73 | 73 | 53 | 55 | 52 | Unsprouted | Trace | None. |
| 8 | 53 | 83 | 87 | 81 | 40 | 42 | 40 | Part barely started<br>Part sprouted, .12 in | Trace | None. |
| 8 | 60 | 49 | 94 | 94 | 59 | 59 | 49 | Sprouted, .12 to .25 in | None | None. |
| 8 | 74 | 47 | 94 | 94 | 78 | 87 | 70 | Barely started | Trace | None. |
| 10 | 25 | 75 | 92 | 92 | 46 | 48 | 44 | Unsprouted | Trace | None. |
| 12 | 22 | 80 | 90 | 89 | 51 | 54 | 51 | Unsprouted | Trace | None. |
| 12 | 54 | 88 | 93 | 93 | 42 | 42 | 42 | Part barely started | None | None. |
| | | | | | | | | Part sprouted, .12 in | None | None. |
| 12 | 62 | 44 | 79 | 79 | 41 | 44 | 41 | Sprouted, .5 in | None | None. |
| 12 | 75 | 67 | 96 | 96 | 65 | 65 | 53 | Sprouted, .12 in | None | None. |
| 14 | 19 | 89 | 98 | 96 | 52 | 53 | 50 | Unsprouted | None | None. |
| 16 | 13 | 65 | 78 | 78 | 46 | 53 | 46 | Unsprouted | None | None. |
| 16 | 16 | 51 | 79 | 79 | 51 | 52 | 49 | Unsprouted | None | None. |
| 16 | 55 | 93 | 94 | 93 | 43 | 43 | 43 | Part barely started | None | None. |
| | | | | | | | | Part sprouted, .12 in | None | None. |
| 16 | 86 | 51 | 104 | 104 | 59 | 59 | 53 | Sprouted, .25 to .5 in | None | None. |

TABLE II.— EFFECT OF FORMALDEHYDE GAS ON POTATO TUBERS: MISCELLANEOUS EXPERIMENTS.*

| Quantity of tubers. | Number of experiment. | Humidity. | | | Temperature. | | | Condition of test tubers before treatment. | Injury. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Initial. | Maximum. | Closing. | Initial. | Maximum. | Minimum. | | Lenticel spotting. | Eye injury. |
| *Tubers* | | *Per ct.* | *Per ct.* | *Per ct.* | *Deg. F.* | *Deg. F.* | *Deg. F.* | | | |
| 20 | 17 | 51 | 76 | 64 | 48 | 55 | 55 | Unsprouted | Considerable | None. |
| 20 | 18 | 70 | 98 | 89 | 55 | 57 | 54 | Unsprouted | Much | Much. |
| 20 | 21 | 70 | 90 | 80 | 51 | 56 | 51 | Slightly sprouted | Considerable | Considerable. |
| 20 | 24 | 59 | 99 | ..... | 50 | 53 | 40 | Slightly sprouted | Much | Much. |
| 23 | 68 | 88 | 95 | 95 | 51 | 52 | 51 | 10 barely started | Considerable | Considerable. |
| | | | | | | | | 13 sprouted, .25 in | Trace | None. |
| 23 | 69 | 95 | 100 | 100 | 52 | 54 | 52 | 10 barely started | Considerable | A little. |
| | | | | | | | | 13 sprouted, .25 in | Trace | None. |
| 23 | 71 | 52 | 93 | 93 | 48 | 50 | 48 | 10 barely started | Considerable | Trace. |
| | | | | | | | | 13 sprouted, .5 in | Trace | None. |
| 23 | 81 | 78 | 97 | 92 | 51 | 55 | 50 | Sprouted, .25 in | Considerable | Much. |
| 23 | 82 | 77 | 96 | 95 | 50 | 54 | 49 | Sprouted, .25 in | Much | Much. |
| *Lbs.* | | | | | | | | | | |
| 4 | 78 | 75 | 93 | 89 | 52 | 54 | 50 | Sprouted, .12 in | Considerable | Much. |
| 3.7 | 87 | ..... | ..... | ..... | 57 | ..... | ..... | Unsprouted | Considerable | None. |
| 3.7 | 88 | ..... | ..... | ..... | 59 | ..... | ..... | Unsprouted | Much | None. |
| 3.7 | 89 | ..... | ..... | ..... | 46 | ..... | ..... | Unsprouted | Considerable | None. |

* Experiments 17 and 21 were made with half the standard quantity of chemicals, viz., 15 cubic centimeters of formaldehyde and 7.15 grams permanganate to 21.56 cubic feet. Time of exposure, 24 hours. Experiments 18, 24 and 78 were made with double the standard quantity of chemicals, viz., 60 cubic centimeters formaldehyde and 28.50 grams permanganate to 21.56 cubic feet. Time of exposure, 24 hours. Experiments 81 and 82 were made with Lister's Fumigator. Time of exposure, 24 hours. Experiments 68, 69 and 71 were made with the standard quantity of chemicals, but the time of exposure was reduced to 3 hours. In experiments 87, 88 and 89 an attempt was made to duplicate the experiments of Jones and Morse (Vt. Sta. Rpt. 18:288). 65.75 cubic centimeters formaldehyde and 24.65 grams potassium permanganate were used in 21.56 cubic feet of space. Time of exposure 24 hours.

HUMIDITY.

All who have had much to do with formaldehyde disinfection recognize the importance of moisture. Numerous investigations have shown that in order to insure efficient disinfection it is necessary to have a comparatively high humidity. In the disinfection of living rooms during cold weather this factor is a very important one because in artificially heated rooms the relative humidity is usually low and special methods must be employed to raise it. A relative humidity of about 60 per ct. is usually considered the minimum for thorough disinfection. According to Dudley and McDonnell it is the *relative* humidity rather than the absolute humidity which is important.[26]

In the disinfection of seed potatoes the humidity factor has been taken into account by Morse [27] who recommends that "just before placing the formaldehyde in the generator the floor of the disinfecting chamber should be thoroughly wet down with boiling water."

Our own studies have dealt with the causes of tuber injury rather than with the efficiency of disinfection, but it seems reasonable to assume that anything which tends to increase the efficiency of disinfection would tend to increase injury to the tubers. If so, raising the relative humidity in the disinfection chamber might be expected to increase the liability of the tubers to injury. As a matter of fact, our experiments seem to show that such is the case, but the evidence is not entirely conclusive. As no means were employed for accurately controlling either the temperature or the humidity, and the factors of quantity and germination were also variable, the experiments were so much complicated that close comparisons are impossible. By an examination of Tables I and II it will be seen that the relative humidity was rather high in all of the experiments. The lowest maximum humidity was 73 per ct. in Experiment 27. In the majority of the experiments the maximum was in the neighborhood of 90 per ct. This may account for the failure of the experiments to show marked effects from changes in humidity.

When small quantities of potatoes are treated the maximum humidity is usually reached in from two to four hours after starting the

[26] Dudley, C. B., and McDonnell, M. E. Disinfection of passenger cars. Reprint from the *American Engineer and Railroad Journal*, June, 1902.

[27] Me. Sta. Bul. 174:325.

generator, and then there follows a marked decline. When the initial humidity is below 80 per ct. there is usually a sudden rise of 15 to 25 per ct. owing to the water vapor produced by the evaporation of the formaldehyde solution. McClintic [28] has expressed the opinion (based on the results of some of his experiments) that the moisture given off by the evaporation of the formaldehyde solution does not answer for disinfection purposes so well as the natural humidity in the atmosphere. The writers have observed nothing which indicates that this is true for tuber injury nor does there seem to be any reason why it should be so. Both chemically and physically the water vapor produced by the evaporation of formaldehyde solution is the same as that in the air.

When large quantities of potatoes are treated the maximum humidity is not usually attained until at or near the end of the 24-hour period. This is probably due to the influence of the moisture produced by the respiration of the tubers.

While the general trend of the relative humidity is as stated above there are frequent exceptions. Changes in temperature, of course, affect the relative humidity considerably and as the disinfection chamber was not perfectly gas-tight changes in the humidity of the outside air, also, had some influence.

Although convinced that a comparatively high relative humidity is necessary for the successful disinfection of seed potatoes by means of formaldehyde gas the writers consider it unnecessary to wet the floor with boiling water as recommended by Morse or to employ any other means to increase the humidity. In cellars and store rooms suitable for seed potatoes the humidity is naturally high, particularly in the spring when the treatment is made. In addition to the natural humidity the evaporation of the formaldehyde solution may be expected to supply from 15 to 25 per ct. and the respiration of the tubers, also, furnishes a considerable amount of moisture. As a matter of course, an artificially heated room would not be used for a disinfection room and in almost any unheated room the humidity may be expected to be ample for the purpose of disinfection.

Experiments made by Jones and Morse[29] indicate that the gas

[28] McClintic, T. B. The limitations of formaldehyde gas as a disinfectant. Pub. Health and Mar. Hosp. Ser. U. S. Hyg. Lab. Bul. 27:110. 1906.

[29] Vt. Sta. Rpt. 17:401.

treatment is more effective upon dry potatoes than upon wet ones. From our own experiments it appears that wetting the tubers increases rather than diminishes the liability of the tubers to injury. In Experiments 1, 2, 3 and 44 some of the test tubers were dry and others wet. In Experiment 44 both lots of tubers were severely injured (completely ruined) without any appreciable difference between the wet and the dry ones; but in the other three experiments the wet tubers showed decidedly more injury than the dry ones. It is also worthy of note that of the six experiments in which the quantity of potatoes was 4 lbs. per cubic foot the greatest amount of injury occurred in No. 84 the only one in which the test tubers were wet. However, the humidity was somewhat higher in this experiment than in any of the others.

In the practical disinfection of seed potatoes the wetting of the tubers is liable to be encountered, sometimes, in an unexpected and annoying manner. Objects transferred from a cool room into warm moist air quickly condense moisture upon their surface and become quite wet. This happens to potatoes when removed from a cool cellar to the warmer air of the disinfection room.

### TEMPERATURE.

Although it is stated by Dudley and McDonnell[30] "that we are fairly safe in ignoring temperature in the matter of disinfection with formaldehyde down to as low, at least, as 32 degrees Fahr." it is generally held that a moderately high temperature (60 degrees Fahr. or more) is essential to thorough disinfection.[31] At lower temperatures a portion of the formaldehyde becomes polymerized, that is, changed into an amorphous white substance called paraformaldehyde which is believed to be useless for purposes of disinfection. McClintic[32] says: "The effects of temperature seem to be principally upon the state of the formaldehyde after it is liberated; that is, below a certain point it polymerizes." In one of his experiments in sleeping cars "at a temperature of 46 degrees Fahr. polymerization was so marked that the deposit of paraform gave the interior furnishings of the car a frosty appearance."[33]

[30] *Loc. cit.*, page 8.

[31] A review of the early literature of this subject is given by Mayer and Wolpert. Zur Rolle der Lufttemperature bei der Formaldehyddesinfektion. *Hyg. Rundschau* 11 : 396–400. 1901.

[32] *Loc. cit.*, page 110.

[33] *Loc. cit.*, page 91.

The following statement by Base[34] appears in his report on the chemical work done in connection with McClintic's investigation: "M. B. Porch (Assistant in Pharmacology, Hygienic Laboratory, Washington), using the same apparatus and methods that I did, but working at lower temperatures, found that polymerization of formaldehyde gas begins at about 62 degrees Fahr., and becomes more marked as the temperature decreases, which is evidenced by the persistent hazy condition of the air of the room, the low percentage yield of formaldehyde, and the deposition of paraformaldehyde in the room. He obtained in the permanganate–formalin method a yield of 25.1 per ct. at 62 degrees Fahr. and 11.1 per ct. at 52 degrees Fahr., as against 38.39 per ct. obtained by me at the higher temperatures of my experiments, namely, 71 degrees and 79 degrees Fahr."

According to Rosenau[35] "the action of the gas seems to be about the same between the temperatures of 10 degrees C. and 27 degrees C. Higher degrees of heat materially aid the disinfecting power of the gas."

Discussing the disinfection of seed potatoes Morse says:[36] "Temperature is an important factor in disinfecting with formaldehyde. It is more effective above 80 degrees Fahr. and disinfection with this gas should never be attempted where the temperature of the chamber used is below 50 degrees Fahr."

In 21 of our experiments the temperature was at or below 50 degrees Fahr. and in two of them below 40 degrees Fahr.; yet more or less injury occurred in 16 of these experiments, being quite severe in some of them. Even in Experiment 32, in which the maximum temperature was 39 degrees Fahr., fully one-half the eyes on the tubers were ruined. Most of the experiments were conducted at temperatures of 50 to 70 degrees Fahr.; temperatures higher than 70 degrees were had in only two experiments, viz. No. 3 in which the maximum temperature was 72 degrees and in No. 74 in which it was 87 degrees Fahr. We were able to obtain the high temperature of 87 degrees only by placing the disinfection chamber

[34] Base, Daniel. Formaldehyde disinfection. Determination of the yield of formaldehyde in various methods of liberating the gas for the disinfection of rooms. *Jour. Am. Chem. Soc.* **28**: 989. 1906.

[35] Rosenau, M. J. Disinfection and disinfectants, p. 90. P. Blakiston's Son & Co. Philadelphia. 1902.

[36] Me. Sta. Bul. 174: 325.

out of doors in the sun on a hot day. In practice, temperatures above 70 degrees Fahr. will be encountered but rarely in New York. The heat generated by the chemical reaction commonly raised the temperature of the disinfection chamber only one or two degrees.

As regards the influence of temperature, the most instructive experiments are those in which the quantity of potatoes treated equalled 8 lbs. per cubic foot. With this quantity the injury is slight and if temperature is a factor of much importance it should be shown here; but we see no evidence of it. Comparing Experiment No. 53 in which the maximum temperature was 42 degrees Fahr. with Experiment No. 74 in which the maximum temperature was 87 degrees Fahr. we find that the injury was practically the same in the two experiments notwithstanding the relative humidity was somewhat higher in the latter than in the former. It should be borne in mind, also, that the temperature of the cellar in which the original case of injury occurred was only 45 degrees Fahr.

In several of the experiments in which the temperature ranged between 40 and 50 degrees pieces of smooth black paper were exposed inside the disinfection chamber. The amount of paraformaldehyde precipitated was sufficient merely to give a faint white-dusty appearance to the paper. In most cases it could be detected only by holding the paper so that the line of vision was nearly parallel with its surface. As no quantitative determinations were made it cannot be stated accurately to what extent such precipitation reduced the quantity of available gas, but some reduction certainly occurred. However, it may be that the loss in gas was offset by the increased adsorption at the lower temperature. It is known that adsorption varies considerably with the temperature. Whatever the explanation, the fact remains that severe injury occurred at temperatures between 40 and 50 degrees Fahr. So far as can be determined from our experiments there is no definite relation, within the limits of temperature likely to be used, between the temperature of the disinfection chamber and tuber injury.

What has been said above on the subject of temperature relates entirely to the temperature of the air in the disinfection chamber. There remains yet to be considered the temperature of the chemicals. In most of our experiments the temperature of the formaldehyde solution at the time of pouring it upon the potassium permanganate crystals was between 60 and 70 degrees Fahr. Probably, the tem-

perature of the potassium permanganate was, in most cases, a little above the initial temperature of the disinfection chamber. Only in two experiments (Nos. 1 and 15) were there any indications that the reaction had not been complete, and in these cases the low temperature of the formaldehyde solution was probably responsible.

For the purpose of securing information on this point the following experiments were made:

*Experiment No. 1.* In a large room in which the temperature of the air was 35 degrees Fahr. two generators were started simultaneously. In one of the generators the temperature of the chemicals at time of mixing was 51 degrees Fahr., in the other, 70 degrees Fahr. In each case 30 cubic centimeters of formaldehyde solution were poured upon 14.25 grams of needle-shaped crystals of potassium permanganate. Although the reaction began earlier and was finished earlier with the warm chemicals the end results appear to have been practically the same, except, possibly, the residue from the warm chemicals was a trifle drier than that from the cool chemicals. For practical purposes both reactions were satisfactory.

*Experiment No. 2.* Thirty cubic centimeters of formaldehyde solution and 14.25 grams of potassium permanganate crystals were exposed in the open air until they had acquired its temperature, viz., 34 degrees Fahr. They were then mixed in a pint tin cup having the same temperature. The mixture effervesced very feebly, barely ruffling the surface, and the reaction was a complete failure.

From these experiments it appears that the success of the reaction depends upon the temperature of the chemicals rather than upon the temperature of the air in the disinfection chamber. Whatever the temperature of the room, good results may be expected whenever the temperature of the chemicals at time of mixing is above 60 degrees Fahr.

### SPROUTING.

In our first three experiments conducted with sprouted tubers during May, 1912, there was much eye injury as well as lenticel spotting exactly as had occurred in the original case of injury. When we began experimenting again in February, 1913, using unsprouted tubers, there was much lenticel spotting but no eye injury. (See Experiments 4, 5, 6, 7, 8, 10, 11, 12 and 13.) By using sprouted and unsprouted tubers in the same experiment it was shown that

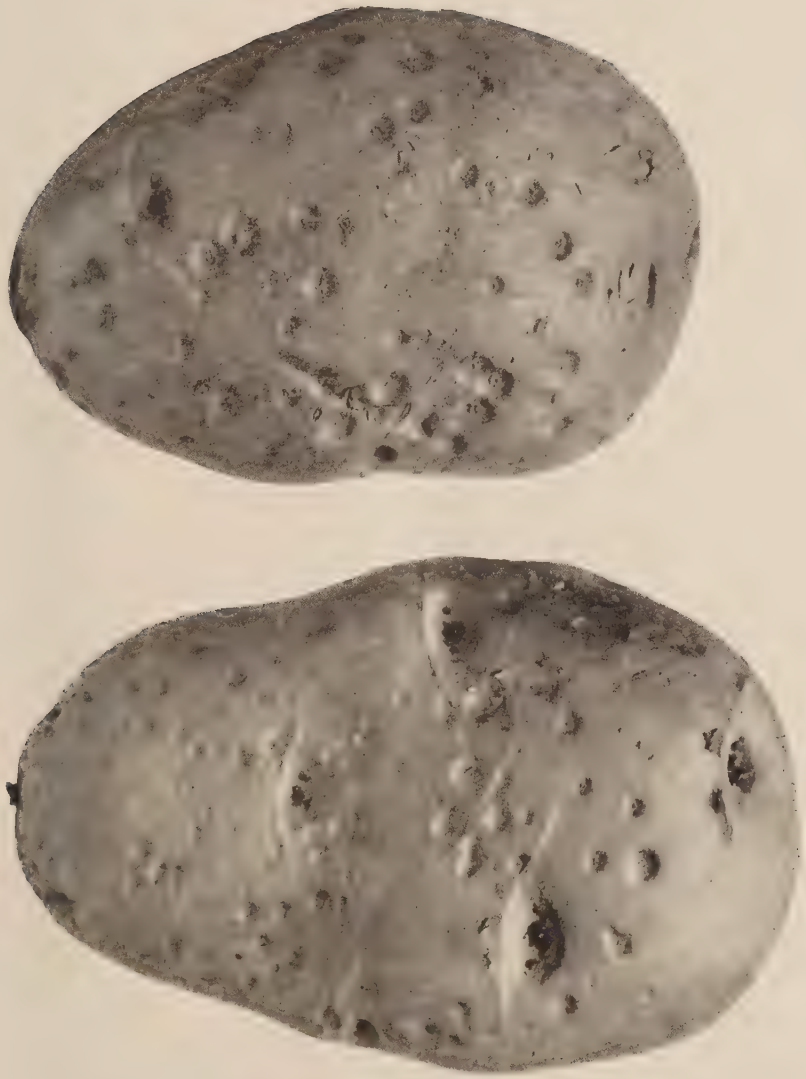

PLATE I.—POTATO TUBERS INJURED BY FUMIGATION WITH FORMALDEHYDE GAS
(Natural size)

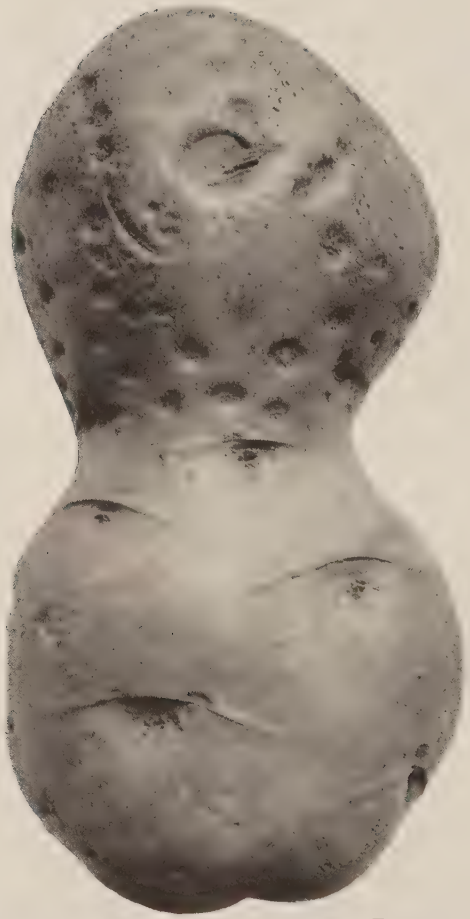

PLATE II.—POTATO TUBER INJURED BY FUMIGATION WITH FORMALDEHYDE GAS: SHOWING LESSER SUSCEPTIBILITY OF THE "SEED" END. See Page 409

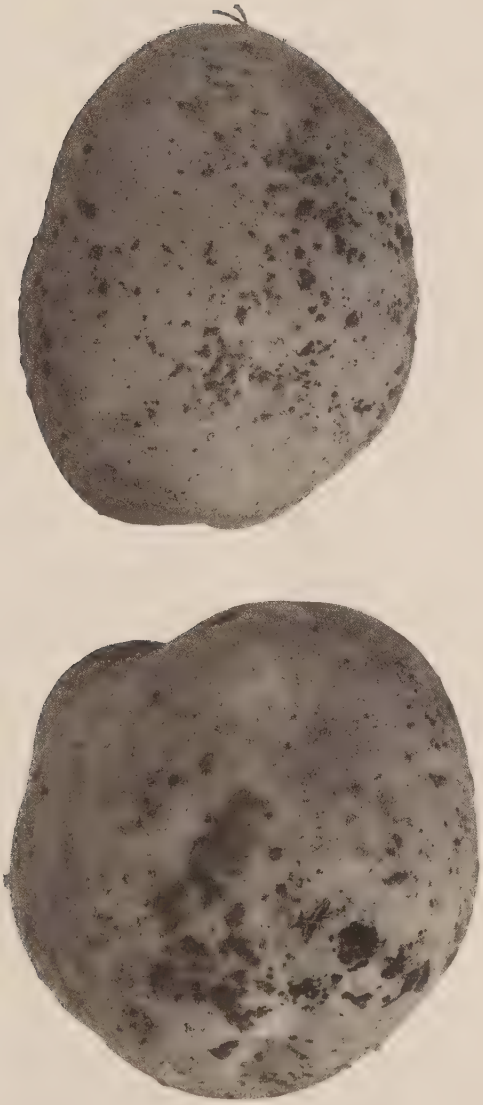

PLATE I.—POTATO TUBERS BEARING RHIZOCTONIA SCLEROTIA. (Natural size)

sprouted tubers are much more susceptible to eye injury than are unsprouted ones. Many such experiments were made and the results were consistent throughout. (See Table I.) The slightest sprouting makes the tubers liable to eye injury. In fact, tubers with sprouts one-eighth of an inch long are more liable to eye injury than tubers with sprouts one-fourth to one-half inch long. Usually, it can be determined within two or three days after treatment whether the eyes have been injured. As a rule, injured eyes are surrounded by a ring of sunken, dead, brown tissue, but there are exceptions in which the eyes have been killed by the treatment yet show no injury to the surrounding skin.

Exposure to light makes the tubers more resistant to lenticel spotting. In numerous cases it was observed that tubers kept in a dimly lighted room for two or three weeks prior to treatment showed less lenticel spotting than tubers kept in a dark cellar. It was observed, also, that lenticel spotting is least severe (i. e., the spots are least numerous) at the bud or seed end of the tuber. Dumb-bell shaped tubers often show this in a striking manner. The tuber shown in Plate II was treated in Experiment No. 5. It bore 85 well-marked spots on the stem-end portion while on the seed-end portion there were only 20 spots and these were mostly small ones.

The probable explanation of this is that there are fewer lenticels on the seed end.

### RELATIVE SUSCEPTIBILITY OF DIFFERENT VARIETIES.

Two crates of potatoes of the variety Rural New Yorker No. 2 which were in the cellar when the original treatment was made showed only traces of injury while the Sir Walter Raleigh potatoes were much injured. The only way in which we could account for this difference was that the variety Sir Walter Raleigh is more susceptible to such injury.

In order to secure some data on the relative susceptibility of different varieties the following experiments were made: In Experiments 9 and 11 potatoes from six different groceries were compared with our own Sir Walter Raleigh. It is not known to what variety any of the grocery potatoes belonged, but they were probably of different varieties. The severity and character of the injury varied somewhat with different lots, but the differences were small. In

Experiment No. 26 potatoes from five other groceries were compared with our Sir Walter Raleigh. The results were the same as in Experiments 9 and 11.

In Experiments 59, 65 and 73 ten varieties (three early and seven late) were compared with our own Sir Walter Raleigh. In the last of these the results were as follows: On five varieties (Twentieth Century, Rural New Yorker No. 2, Gold Coin, Sir Walter Raleigh from Honeoye Falls and Sir Walter Raleigh from Geneva) lenticel spotting was severe; on the other six varieties (Carman No. 3, Green Mountain, Ionia, Northern Beauty, Early Rose and Irish Cobbler) there was less, but considerable, lenticel spotting, Irish Cobbler showing the least. Eye injury was severe on all lots without any appreciable difference. In Experiment 88 lenticel spotting was considerably more severe on Gold Coin than on Sir Walter Raleigh and in Experiment 89 Rural New Yorker No. 2 was injured considerably more than Sir Walter Raleigh. The conclusion reached is that varieties may vary somewhat in their susceptibility to injury, but Sir Walter Raleigh is not more susceptible than some other common varieties.

### SOME OTHER POSSIBLE FACTORS.

In the original case of injury it was observed that tubers exposed on the tops of the crates were severely injured while those on the interior of the crates were but slightly injured, if at all. Even tubers on the sides of the crates opposite the openings between the slats were much less injured than those on the top. This led to the suspicion that some substance precipitated from the air was chiefly responsible for the injury. In Experiment 1 three tubers were placed under an inverted glass dish in such manner that nothing could fall upon them from above. As these tubers were quite as much injured as unprotected tubers further experiments were not made. Whatever the explanation of the greater injury to tubers on the tops of the crates the phenomenon is worthy of note because it shows that tubers on the interior of the crates are much less liable to injury than those on the top. Presumably, there is a corresponding difference in the efficiency of the treatment. It is plain that uniform results will be obtained only when the tubers are exposed in very thin layers.

Another possible factor is the position of the tubers in the disinfection room. In most of our experiments the test tubers lay on the floor of the disinfection chamber. Also, in the original case of injury the crates of potatoes were all near the floor. Are tubers on the floor more, or less, liable to injury than tubers near the ceiling? According to Mayer and Wolpert[37] the concentration of the formaldehyde gas decreases from the ceiling downward and more thorough disinfection occurs at the ceiling than at the floor. In the single experiment (No. 23) conducted by us tubers on the floor were quite as severely injured as those near the ceiling.

Morse's caution to avoid placing tubers directly above the generator appears to be well founded. In one of our Experiments (No. 1) two tubers suspended in a wire basket $6\frac{1}{2}$ in. above the generator were much more severely injured than tubers on the floor of the disinfection chamber. However, this can not have been a factor in the cellar experiment because none of the potatoes were above a generator or nearer than 2.5 feet to one. Provided the tubers are not over the generator it does not matter how near they are to it. In our experiments the generator was a pint tin cup. It was observed repeatedly that tubers lying on the floor within one inch of the generator were no more injured than those in the farthest corner of the chamber.

Any break in the skin of the tuber increases the liability to gas injury at that point. When pins are stuck into the tubers before treatment a sunken area of dead brown tissue appears around each pin. However, we believe Wollenweber to be in error when he says that the effect of formaldehyde is a test as to whether or not the skin is wounded.[38] If that be true there is no such thing as an unwounded potato because any potato treated with formaldehyde gas in the manner we have described will show the sunken, dead, brown spots.

That the gas enters by way of the lenticels is very plain in some cases and obscure in others. On potatoes grown in wet heavy soil the lenticels become abnormally developed. When the tubers are first dug such lenticels are plainly visible to the unaided eye as small white specks and they are readily detected even after the

[37] Mayer, E., und Wolpert, H. Beiträge zur Wohnungs-desinfektion durch Formaldehyd. *Hyg. Rundschau* **11**: 157. 1901.

[38] Wollenweber, H. W. Studies on the Fusarium problem. *Phytopathology* **3**: 43. 1913.

tubers have been long in storage. It occurred to us that such development of the lenticels might make the tubers more liable to gas injury, but we could find no evidence that such is the case.

It has been established that the quantity of formaldehyde gas evolved varies somewhat according to the proportions in which the chemicals are mixed. Several investigators have attempted to determine the most economical ratio of permanganate to formaldehyde, but if we are to judge by the recommendations of state boards of health in the United States they have not succeeded in fully solving the problem. Several different formulas are in use. But this is not a factor in our present problem because the proportions used at the time of our disastrous experience with the gas treatment, also in nearly all of our experiments, were those used by Morse in his experiments, viz., .475 gram of permanganate to each cubic centimeter of formaldehyde solution, which is the ratio recommended by Evans.[39]

Since our experiments have shown that the quantity of potatoes per cubic foot is a factor of prime importance the question naturally arises as to the advisability of varying the quantity of formaldehyde according to the quantity of potatoes. Undoubtedly, this must be done if uniform results are to be obtained, but the few experiments which we have made do not warrant us in making recommendations as to just how it should be done. In three of our experiments (Nos. 18, 24 and 78) the standard quantity of formaldehyde was doubled and in two others (Nos. 17 and 21) it was halved. (See Table II.) The tuber injury in Experiment No. 78, in which four pounds per cubic foot were treated with double the standard dose, was practically the same as in Experiments 79 and 83 in which half this quantity (2 lbs. per cubic foot) were treated with the standard dose.

In room disinfection 3 or 4 hours' exposure is usually deemed sufficient. In three of our experiments (Nos. 68, 69 and 71, Table II) the length of exposure was only three hours. The amount of tuber injury was appreciably less than in comparable experiments in which the exposure was 24 hours.

[39] *Loc. cit.*

## SIMILAR INJURY PRODUCED BY OTHER GASES AND LIQUIDS.

Tubers exposed to the fumes of ammonia, bromine or ether show depressed brown spots almost exactly like those resulting from fumigation with formaldehyde gas. According to Orton and Field a similar spotting may be produced by fumigation with sulphur.[40] In our experiments, dipping or soaking the tubers in strong solutions of formaldehyde and corrosive sublimate has had the same effect. In mild cases of injury only lenticel spotting occurred, while in more severe ones there was also eye injury as with tubers injured by treatment with formaldehyde gas. With the strengths commonly used in treating potatoes for scab, viz., one pint of 40 per ct. formaldehyde to 30 gals. of water (1 to 240) and one ounce of corrosive sublimate to 7 gals. water (1 to 1000, approximately), no spotting of any kind has been observed by us or by any one else so far as can be determined from the literature of the subject. Tubers dipped in 37 per ct. formaldehyde and those which were soaked two hours in 18 per ct. and 9 per ct. solutions showed both lenticel spotting and eye injury. Solutions of from 2 to 9 per ct. strength usually produced only lenticel spotting, although in one case some eye injury resulted from the use of a $1\frac{1}{2}$ per ct. solution on sprouted tubers. When the dilution was below one per ct. no spotting occurred.

With corrosive sublimate some lenticel spotting occurred when tubers were soaked one and one-half hours in solutions as weak as 1 to 200.[41] In saturated solutions (1 to 16) and a 1 to 25 solution there was both lenticel spotting and eye injury.

## FORMALDEHYDE GAS CAUSES SPOTTING AND BROWNING OF APPLES.

Some apples which were in the cellar at the time the original case of injury occurred showed severe lenticel spotting — circular, brown spots, 1 to 3 millimeters in diameter, surrounding the lenticels. Similar spotting, also a browning of the skin, occurred subsequently in several of our potato fumigation experiments in which a few apples were introduced into the fumigation chamber. On Rome

[40] Orton, W. A., and Field, Ethel C. Sulphur injury to potato tubers. *Science* 31:796. 20 My 1910.

[41] One gram of corrosive sublimate dissolved in 200 cubic centimeters of distilled water.

apples the injury usually appeared in the form of lenticel spotting while on Baldwin it more frequently resembled "scald," a trouble of stored apples in which the skin becomes brown over large irregular areas with indistinct boundaries.

That formaldehyde, also ammonia, may cause lenticel spotting of apples has been announced previously by Norton[42] who points out that on the variety Jonathan the injury closely resembles the Jonathan fruit spot disease described by Scott.[43]

## EFFECT ON GERMINATION AND GROWTH.

Throughout this bulletin lenticel spotting is referred to as injury and when no lenticel spotting occurred it has been stated that there was no injury. The question naturally arises, are tubers which show only lenticel spotting really injured for seed purposes? It may also be asked if tubers which show no lenticel spotting are certainly unharmed for use as seed. Our experiments have not been carried far enough to enable us to answer these questions fully. The sprouting of the tubers has been observed in all of the experiments and in a few of the experiments the tubers were planted in the greenhouse and kept under observation until the plants were about six inches high, but none were followed through to maturity. Judging from the observations made we are of the opinion that there may be considerable lenticel spotting without material injury to the tubers for seed. No matter how severe the lenticel spotting, sprouting usually appears to proceed normally provided there are no areas of dead brown tissue surrounding the eyes. However, exceptions to this have been seen occasionally. Treated tubers which are free from lenticel spotting may be regarded as safe for planting.

## IS FORMALDEHYDE SOLUTION WEAKENED BY REPEATED USE?

The discovery that potatoes exposed to formaldehyde gas adsorb or hold upon their surface large quantities of the gas caused the writers to inquire if in the liquid treatment of potatoes for scab the formaldehyde solution might not be materially weakened by repeated use through the removal of formaldehyde adsorbed by the

[42] Norton, J. B. S. Jonathan fruit spot. *Phytopath.* 3:99–100. Ap. 1913.
[43] Scott, W. M. A new fruit spot of apple. *Phytopath.* 1:32–34. F. 1913.

tubers. Accordingly, the following experiment was made: Eighty cubic centimeters of 37 per ct. formaldehyde solution were mixed with 1600 cubic centimeters of distilled water thereby making a 1-to-21 solution. Ten successive lots of unsprouted tubers were each soaked two hours in this solution. Each lot contained as many tubers as the solution would cover, i. e., the solution was used to its full capacity each time. The total number of tubers treated was 165 and their total weight 41¾ lbs. The tubers were thoroughly washed before treatment. With different lots the temperature of the solution varied from 17 to 22 degrees C. After treatment the tubers were dried and then stored in a dimly-lighted room. The tubers of all ten lots showed slight lenticel spotting, Lot No. 10 being quite as much affected as Lot No. 1. Lots No. 1 and 10 were kept under observation for 16 days. Both lots sprouted vigorously and, apparently, in a normal manner. So far as could be determined from the effect on the tubers the strength of the formaldehyde solution had not been weakened. This conclusion is confirmed by the results of chemical analyses made by the Chemical Department of the Station. The solution which had been used ten times was found to contain 2.01 per ct. formaldehyde while a portion of the solution which had not been used contained 2.02 per ct. formaldehyde.

## HOW SHOULD THE FORMALDEHYDE GAS TREATMENT BE MADE?

In the light of this investigation how should the formaldehyde gas treatment be applied? First of all, it may be said that the gas treatment should be used only in cases in which it is impracticable to use either of the liquid treatments. The safety and efficiency (for scab) of the liquid treatments have been thoroughly established. With our present knowledge, the gas treatment as recommended by Morse may be applied with entire safety provided *the fumigation chamber contains at least ten pounds of potatoes per cubic foot of space;* but it is uncertain what effect this will have on the efficiency of the treatment. That it is possible to secure efficiency without injury to the tubers is indicated by Morse's experiment at Houlton, Maine, although as Morse himself states,[44] the fact that so little scab (6.5 per ct.) developed from the untreated seed detracts somewhat from

[44] Me. Sta. Bul. 149 : 313.

the value of the results. In this experiment the quantity of potatoes was slightly above ten pounds per cubic foot. The experiment made by Jones and Morse[45] at the Vermont Station in 1905 gave more decisive results, but in this experiment the quantity of potatoes was somewhat less than 3.7 lbs. per cubic foot and the quantity of formaldehyde more than twice that of the standard formula. Further evidence that efficiency is not incompatible with safety is furnished by the earlier experiments of Jones and Morse, but these, also, were made with smaller quantities of potatoes and the gas was not generated by the permanganate method.

If, upon further investigation, it should be found (as we believe it will be) that a moderate amount of lenticel spotting does not injuriously affect germination or growth, the quantity of potatoes may be safely lowered to 5 lbs. per cubic foot (83 bushels per 1000 cubic feet).

As stated on a previous page, *uniform results as regards safety and efficiency can be obtained only by varying the quantity of chemicals according to the quantity of potatoes per cubic foot.* Further investigation is needed to determine definitely the terms of this relation. At present, it can only be said that with the standard formula of 3 pints of formaldehyde and 23 ounces of permanganate to 167 bushels of potatoes in 1000 cubic feet (10 lbs. per cubic foot) there will be no injury to the tubers and, probably, scab will be fairly well controlled.[46] No other proportions can be confidently recommended. It is probable that doubling or halving the quantity of both chemicals and potatoes will give similar results, but further experiments are necessary to establish this.

Aside from what is said above concerning the quantity of potatoes per cubic foot of space we approve the directions for treatment given by Morse in Maine Station Bulletins 141, 149 and 174 except, perhaps, in one respect, viz., the advisability of exposing the tubers in ordinary bushel crates. According to our observation the gas does not readily penetrate to the interior of bushel crates. More uniform results would be obtained if the tubers were exposed in slatted bins only a few inches deep and so arranged that the gas can circulate freely above and below them.

[45] Vt. Sta. Rpt. 18 : 287–291.

[46] This statement in regard to the efficiency of the treatment is based on the results of Morse's experiment at Houlton, Me.

BULLETIN No. 370.

# THE EFFICIENCY OF FORMALDEHYDE IN THE TREATMENT OF SEED POTATOES FOR RHIZOCTONIA.

W. O. GLOYER.

## SUMMARY.

The object of this investigation was to determine the relative efficiency of the standard scab treatments in the disinfection of seed potatoes affected with Rhizoctonia. Experiments were made with formaldehyde gas, formaldehyde solution, and corrosive sublimate solution.

It was found that neither formaldehyde gas nor formaldehyde solution can be depended upon to kill all of the Rhizoctonia sclerotia. The principal reason for this appears to be the inability of the formaldehyde to penetrate readily to the center of the larger and more compact sclerotia. Also, the efficiency of the gas treatment depends to a considerable extent upon the quantity of tubers per cubic foot of space in the disinfection chamber. Other things being equal, the smaller the quantity of potatoes the greater the efficiency. Neither temperature nor humidity are factors of much importance.

The standard corrosive sublimate treatment, on the contrary, is thoroughly efficient. Even with a 1-to-2000 solution (half standard strength) all Rhizoctonia sclerotia are killed.

The conclusion reached is, that when it is desired to treat seed potatoes for Rhizoctonia the corrosive sublimate treatment should be used.

## INTRODUCTION.

The numerous fumigation experiments made in the course of the investigation reported in Bulletin No. 369 of this Station offered an excellent opportunity for observing the effect of formaldehyde gas on the Rhizoctonia adhering to potato tubers. Potatoes in various quantities and under various conditions of temperature and moisture were subjected to the formaldehyde gas treatment, and the effect on Rhizoctonia noted. In other experiments Rhizoctonia-infested tubers were dipped in solutions of formaldehyde and corrosive sublimate as

recommended for the prevention of scab. The effect of the treatment was determined by comparing the growth of the Rhizoctonia in artificial cultures made before and after treatment. In this respect, our methods differ from those used by previous investigators. Heretofore, the efficiency of the treatment has been determined, in most cases, by means of field experiments and the results have been more or less unsatisfactory. They have been affected by outside factors such as climatic conditions, texture and drainage of the soil, insects and other fungus diseases. By the culture method such factors are eliminated.

## THE DISEASE.

The disease under consideration is that caused by *Rhizoctonia solani* Kühn which is the sterile form of *Corticium vagum* B. & C. var. *solani* Burt.[1] It has been known in Europe for many years. Its occurrence in America was first reported by Duggar and Stewart [2] in 1901, and it is now found in all portions of this country where the potato is extensively grown. It is recognized on the surface of the tubers by the masses of resting mycelium or sclerotia. These sclerotia-like bodies are often overlooked, for they may be mistaken for soil clinging to the potato. By immersing the tubers in water or washing them free from all soil, the sclerotia can readily be distinguished as dark brown bodies which cling tenaciously to the surface of the tuber. Plate I shows a tuber with the sclerotial bodies upon it. When the fungus is in this form it is of little importance as the tubers are not injured by it, but affected tubers may disseminate the disease, and in very bad cases the market value of the tubers may be lowered.

To this fungus is attributed, to a great degree, the so-called "skips" in the planted row. Rolfs,[3] in 1902 and 1904, held it responsible for the failure of potato crops in Colorado. The fungus may live on the organic matter in the soil or it may live as a parasite attacking the stems, stolons, or roots of the plants. At the point of attack, cankers are formed which in time may increase so

[1] Probably the same as *Hypochnus solani* Prill. & Delacr. (Clinton, Conn. Sta. Rpt. for 1904 : 326; Riehm, *Mitt. K. Biol. Anst. f. Land u. Forstw*, 11 ; 23. 1911).

[2] Duggar, B. M., and Stewart, F. C. The Sterile Fungus Rhizoctonia. Cornell Sta. Bul. 186. 1901; also N. Y. (Geneva) Sta. Bul. 186. 1901.

[3] Rolfs, F. M. Potato Failures. Colo. Sta. Bul. 70. 1902; and Bul. 91. 1904.

as to girdle the plant or separate portions from the main stem. That a wound appears to be necessary for the fungus to enter the tissue is suggested by Clinton's [4] observations. He has found the "inconspicuous grayish mealy growth" of the Corticium or fruiting stage on the stalks of the potatoes near the surface of the ground, and no injury was done to the stem at that point. He visited several fields and found that 15 to 20 per ct. of the plants showed this condition. To this same fungus Selby [5] attributes the rosette of the potato, and Rolfs [6] reports that the occurrence of aerial tubers may be explained partially by its presence. However there is no doubt that other factors may bring about similar effects.

## PREVIOUS LITERATURE.

Since Loew's discovery [7] of the germicidal action of formaldehyde, in 1888, a great deal has been written on the subject of fumigation and disinfection for bacteria and fungi. The disinfection of seed potatoes was first taken up by Bolley [8] who has recommended the use of corrosive sublimate (mercury bichloride) solution for potato scab. Later, Arthur [9] found that a formaldehyde solution gave just as good results and was safer to handle. These experiments have been repeated and the conclusions confirmed by numerous other experimenters. The formaldehyde gas treatment for seed potatoes orginated with Jones and Morse as described in Bulletin No. 369, page 386.

It is generally taken for granted that the treatment made for scab is also effective in killing Rhizoctonia. Rolfs [10] conducted extensive field tests of the dip method of treating Rhizoctonia, and concluded that the mercury bichloride solution was effective in controlling it; also that formaldehyde solution gave less favorable results. Selby,[11] in his first report on the potato rosette (which

[4] Clinton, G. P. Report of Botanist. Conn. Sta. Rpt. for 1904:325.
[5] Selby, A. D. A Rosette Disease of Potatoes. Ohio Sta. Buls. 139 and 145. 1903.
[6] *Loc. cit.* Bul. 70.
[7] Loew, O. Physiologische Notizen über Formaldehyd. Ber. Gesell. Morph. u. Phys. zu Munchen. 1888.
[8] Bolley, H. L. Potato Scab and Possibilities of Prevention. N. Dak. Sta. Bul. 4. 1891.
[9] Arthur, J. C. Formaldehyde for Prevention of Potato Scab. Ind. Sta. Bul. 65. 1897.
[10] *Loc. cit.* Bul. 91.
[11] *Loc. cit.* Bul. 139:58.

he attributed to Rhizoctonia), believes the formalin more effective than the corrosive sublimate bath. He has noted the yields of the treated and untreated tubers and used the appearance of the foliage as a criterion in determining the effectiveness of the treatment. He states, "the warranted conclusion, drawn from tests of two seasons (1901 and 1902) with formalin and the extended work of many seasons at the Station with corrosive sublimate appears to be that corrosive sublimate seed treatment does not prevent the Rhizoctonia disease to any appreciable extent, while the formalin seed treatment, as shown conspicuously by study of the growing plants and usually in the yields of tubers, does prevent the disease to a very marked extent." In Selby's second report [12] of his investigations on the treatment of Rhizoctonia, there are recorded experiments in which treated and untreated tubers were planted in infected soil as well as in soil in which the disease was not supposed to be present. The Carman variety is the only one that received treatment with the standard substances and was planted in infected soil and grown apparently under similar conditions. He used formalin at the rate of one pound (pint) to 30 gallons of water, immersing the tubers for two hours. It is uncertain what strength of mercury bichloride solution was used for he states, "the usual strength of one ounce to 16 gallons of water was employed," and in this solution the tubers remained for one hour. However, this is one-half the strength used by Bolley [13] who recommends one ounce to $7\frac{1}{2}$ gallons of water, and an immersion for $1\frac{1}{2}$ hours. The average yields from the check, formalin, and corrosive sublimate treated plots are calculated at 139.9, 131.4, and 127.1 bushels per acre, and the percentages of harvested tubers showing Rhizoctonia are 62, 46, and 29.5 per ct., respectively. The yields from the treated tubers are slightly smaller than those from the untreated, but the least percentage of Rhizoctonia is found on the product of tubers treated with mercury bichloride solution.

Selby also treated Rhizoctonia-infested tubers with formaldehyde solution for various periods of time. The Early Trumbull variety was immersed in standard formalin solution for 2, $3\frac{1}{2}$, and $4\frac{1}{2}$ hours and planted in infected soil under apparently similar conditions. The check plots showed 94 per ct. of the harvested tubers infected with Rhizoctonia, while the tubers treated for 2, $3\frac{1}{2}$, and $4\frac{1}{2}$ hours

[12] *Loc. cit.*
[13] *Loc. cit.*

showed 87, 45, and 48 per ct. of the tubers attacked by it. Though no comment was made on these results it appears that a longer immersion than two hours is more effective in killing the fungus.

Güssow [14] conducted field experiments in which lots of seed tubers attacked by Rhizoctonia were immersed for 3 hours in a solution of one part mercury bichloride to 2000 parts of water (equal to 1 ounce to 15 gallons of water), and, also in a bath of formalin made up of one half pint to 15 gallons of water. At the harvest it was found that the tubers treated with formalin were almost as badly covered with Rhizoctonia as were the original potatoes, while those immersed in mercury bichloride solution were practically free.

## PRESENT TESTS.

### METHODS.

To ascertain the efficiency of the formaldehyde gas, three or more Rhizoctonia-infected potatoes were placed in the fumigator along with the various quantities of tubers that were used in the experiments made for the determination of factors involved in tuber injury. The chemicals used, the fumigator, the quantity of tubers, and the conditions of moisture and temperature under which these experiments were conducted are described in Bulletin No. 369.

For comparison with the results obtained by the gas method of treating seed potatoes, experiments were also conducted in which the standard immersion or dip methods were employed. Rhizoctonia-diseased tubers were immersed in solutions of formaldehyde and mercury bichloride for 2 and $1\frac{1}{2}$ hours respectively. The standard strength of formalin was used unless otherwise noted, namely, one pint of formalin (a 37 per ct. solution of formaldehyde) to 30 gallons of water. Of mercury bichloride, two different strengths were used, namely, one part of the salt to 1000 and 2000 parts of water. The latter strength is one-half that usually employed in practical disinfection. After immersion in these solutions the potatoes were permitted to drain and dry under sterile conditions.

Before and after each experiment cultures were made of the untreated and treated sclerotia to determine the efficiency of the treatment. In making these cultures the usual precautions were used to maintain sterile conditions in handling instruments, petri

[14] Güssow, H. T. Canada Expt. Farms Rpts. 1912:200.

dishes, potatoes, etc. At the outset, sclerotia were placed on potato agar of one per ct. acidity, but it was found that the plates were soon overrun by the potato bacillus. This was generally the case when sclerotia from untreated or formaldehyde-treated tubers were taken. The spores of this bacillus (*Bacillus vulgatus* Trevisan) are very resistant, and are invariably found on potatoes. An idea of their resistance can be secured from the fact that the usual method of obtaining this organism is by boiling potatoes for one-half hour, halving them, and incubating in a sterile moist chamber.[15] These bacteria were kept down by adding two drops of 50 per ct. lactic acid to each tube of about 10 cubic centimeters of the medium. By omitting the lactic acid, the effect of the treatment on the bacteria that are found in the sclerotia and on the surface of the tuber was determined.

That Rhizoctonia on acidulated agar grows well without interference from bacteria has been noted by Duggar and Stewart.[16] However, Duggar later states that Rhizoctonia is apparently not readily affected by weak alkalies or acids.[17] F. C. Stewart, in some of his unpublished work on the carnation Rhizoctonia, has shown that the growth of the fungus is more rapid on agar which is slightly acid than on neutral or slightly alkaline media, while on more strongly acidulated agar the growth again becomes less rapid. In the writer's work it was found that when two drops of 50 per ct. lactic acid were added to a tube containing about 10 cubic centimeters of one-per-ct. acid potato agar, the growth of potato Rhizoctonia was about one-half as fast as on the same medium without the lactic acid. In Tables I–III these two kinds of agar are designated as "strongly acid agar" and "agar, one per ct. acid."

Generally, five sclerotia were placed in each petri dish and allowed to develop at room temperature. After three to five days the nature of the results from the untreated sclerotia could be ascertained. In case of the treated sclerotia, the cultures were examined from time to time and kept ten days before they were discarded. At the end of ten days the cultures were examined by means of the low power of the microscope.

---

[15] Frost. Laboratory Bacteriology, p. 95. 1909.
[16] *Loc. cit.* N. Y. (Geneva) Sta. Bul. 186 : 7.
[17] Duggar, B. M. Fungous Diseases of Plants, p. 453. 1909.

Table I shows the results of the cultures made from sclerotia taken from untreated tubers and tubers subjected to the formaldehyde gas treatment. Unless otherwise stated, the quantities of the chemicals used in the fumigator are 14.25 grams of potassium permanganate and 30 cubic centimeters of formalin, which is equal to 23 ounces of the salt and 3 pints of the liquid for every 1000 cubic feet of space. The exposure was usually for 24 hours and any change in exposure is noted. Where the quantity is expressed in pounds, it is to indicate the number of pounds of tubers per cubic foot of space in the fumigator; otherwise, the number given shows the total number of tubers exposed at one charge. As each experiment is numbered, the condition of the potatoes before they went into the fumigator and the effect of the gas upon them can be readily learned by referring to the corresponding experiments in Tables I and II, Bulletin No. 369. The data in regard to the efficiency of the gas treatment are summarized in Table II of the present bulletin; while Table III shows the results of experiments in which the liquid treatment was used.

TABLE I.—EFFECT OF FORMALDEHYDE GAS ON THE SCLEROTIA OF RHIZOCTONIA.

| QUANTITY OF POTATOES. | TREATED. | | | | | | | | | | | | UNTREATED. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of experiment. | HUMIDITY. | | | TEMPERATURE. | | | NUMBER OF CULTURES ON STRONGLY ACID AGAR.* | | | | | AGAR, 1 PER CT. ACID. | | NUMBER OF CULTURES ON STRONGLY ACID AGAR. | | | |
| | | Initial. | Maximum. | Closing. | Initial. | Maximum. | Minimum. | Sterile. | Showing growth of Rhizoctonia. | Other fungi. | Total. | Percentage Rhizoctonia. | Bacterial colonies. | Sterile. | Sterile. | Showing growth of Rhizoctonia. | Other fungi. | Total. | Percentage Rhizoctonia. |
| *Tubers.* | | *Per ct.* | *Per ct.* | *Per ct.* | *Deg. F.* | *Deg. F.* | *Deg. F.* | | | | | *Per ct.* | | | | | | | *Per ct.* |
| 36 | 59 | 45 | —— | 77 | 50 | 58 | —— | 13 | 2 | 0 | 15 | 13 | 4 | 1 | 1 | 12 | 2 | 15 | 80 |
| 36 | 65 | 48 | 88 | 79 | 63 | 66 | 57 | 15 | 0 | 0 | 15 | 0 | 0 | 5 | 2 | 2 | 6 | 10 | 20 |
| 23 | 72 | 71 | 96 | 83 | 53 | 61 | 53 | 15 | 0 | 0 | 15 | 0 | —— | —— | 0 | 9 | 6 | 15 | 60 |
| 23 | 73 | 50 | 89 | 82 | 68 | 71 | 60 | 15 | 0 | 0 | 15 | 0 | —— | —— | 1 | 6 | 3 | 10 | 60 |
| *Lbs. per cu. ft.* | | | | | | | | | | | | | | | | | | | |
| 1.5 | 50 | 66 | 85 | 78 | 55 | 63 | 55 | 15 | 0 | 0 | 15 | 0 | 3 | 2 | 0 | 8 | 7 | 15 | 53 |
| 1.5 | 67 | 46 | 78 | 78 | 69 | 69 | 58 | 11 | 4 | 1 | 15 | 26 | 1 | 4 | 0 | 4 | 11 | 15 | 26 |
| 1.5 | 76 | 79 | 91 | 86 | 54 | 56 | 53 | 13 | 2 | 0 | 15 | 13 | —— | —— | 1 | 10 | 4 | 15 | 66 |
| 1.5 | 80 | 66 | 82 | 70 | 50 | 51 | 49 | 15 | 0 | 0 | 15 | 0 | —— | —— | 0 | 14 | 1 | 15 | 93 |
| 1.5 | 85 | 69 | 91 | 77 | 54 | 54 | 51 | 15 | 0 | 0 | 15 | 0 | —— | —— | 0 | 10 | 5 | 15 | 66 |
| 2 | 45 | 53 | 84 | 85 | 53 | 57 | 49 | 13 | 1 | 1 | 15 | 7 | 5 | 0 | 0 | 4 | 11 | 15 | 26 |
| 2 | 52 | 85 | 85 | 73 | 40 | 42 | 40 | 11 | 4 | 0 | 15 | 26 | 5 | 0 | 0 | 10 | 5 | 15 | 66 |
| 2 | 56 | 70 | 92 | 86 | 43 | 46 | 43 | 13 | 1 | 1 | 15 | 7 | —— | —— | 0 | 13 | 2 | 15 | 86 |
| 2 | 79 | 62 | 81 | 74 | 49 | 50 | 48 | 5 | 4 | 6 | 15 | 26 | —— | —— | 0 | 15 | 0 | 15 | 100 |
| 2 | 83 | 89 | 94 | 90 | 50 | 51 | 49 | 15 | 0 | 0 | 15 | 0 | —— | —— | 0 | 9 | 6 | 15 | 60 |
| 3 | 43 | 54 | 84 | 78 | 54 | 60 | 54 | 20 | 0 | 0 | 20 | 0 | 0 | 5 | 2 | 6 | 7 | 15 | 40 |
| 3 | 51 | 60 | 77 | 77 | 45 | 46 | 40 | 15 | 0 | 0 | 15 | 0 | 5 | 0 | 0 | 9 | 1 | 10 | 90 |
| 3 | 57 | 77 | 89 | 85 | 46 | 50 | 46 | 14 | 0 | 1 | 15 | 0 | 5 | 0 | 0 | 12 | 3 | 15 | 80 |
| 3 | 61 | 58 | 89 | 87 | 48 | 48 | 37 | 10 | 4 | 1 | 15 | 27 | 4 | 1 | 0 | 13 | 2 | 15 | 86 |
| 3 | 63 | 58 | 80 | 78 | 47 | 55 | 47 | 7 | 5 | 3 | 15 | 33 | 2 | 3 | 0 | 15 | 0 | 15 | 100 |
| 3 | 64 | 64 | 86 | 83 | 65 | 65 | 55 | 15 | 0 | 0 | 15 | 0 | 5 | 0 | 0 | 13 | 2 | 15 | 86 |
| 3 | 66 | 51 | 80 | 78 | 69 | 69 | 61 | 7 | 2 | 1 | 10 | 20 | 5 | 0 | 0 | 7 | 3 | 10 | 70 |
| 4 | 42 | 61 | 87 | 76 | 54 | 58 | 53 | 15 | 0 | 0 | 15 | 0 | 5 | 0 | 0 | 7 | 8 | 15 | 47 |
| 4 | 47 | 66 | 77 | 76 | 62 | 68 | 62 | 15 | 0 | 0 | 15 | 0 | 5 | 0 | 0 | 7 | 8 | 15 | 47 |
| 4 | 58 | 62 | 91 | 91 | 49 | 50 | 45 | 9 | 5 | 1 | 15 | 33 | 5 | 0 | 0 | 15 | 0 | 15 | 100 |
| 4 | 70 | 59 | 88 | 88 | 47 | 51 | 47 | 12 | 3 | 0 | 15 | 20 | —— | —— | 0 | 10 | 5 | 15 | 66 |
| 4 | 77 | 80 | 89 | 83 | 53 | 55 | 52 | 12 | 3 | 0 | 15 | 20 | —— | —— | 0 | 14 | 1 | 15 | 93 |
| 4 | 84 | 90 | 96 | 91 | 50 | 52 | 50 | 13 | 1 | 1 | 15 | 7 | —— | —— | 1 | 12 | 2 | 15 | 80 |

*The acidulation of media is described on page 422.

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 41 | 60 | 90 | 89 | 54 | 57 | 54 | 15 | 0 | 0 | 15 | 0 | 5 | 0 | 2 | 4 | 9 | 15 | 27 |
| 6 | 29 | 40 | 74 | 73 | 64 | 67 | 57 | 20 | 0 | 0 | 20 | 0 | —— | —— | 6 | 3 | 6 | 15 | 33 |
| 8 | 27 | 62 | 73 | 73 | 53 | 55 | 52 | 24 | 1 | 0 | 25 | 4 | 5 | 0 | 4 | 10 | 7 | 21 | 47 |
| 8 | 53 | 83 | 87 | 81 | 40 | 42 | 40 | 11 | 3 | 1 | 15 | 20 | 5 | 0 | 1 | 6 | 8 | 15 | 40 |
| 8 | 60 | 49 | 94 | 94 | 59 | 59 | 49 | 9 | 6 | 0 | 15 | 40 | 5 | 0 | 0 | 14 | 1 | 15 | 93 |
| 8 | 74 | 47 | 94 | 94 | 78 | 87 | 70 | 34 | 5 | 1 | 40 | 12.5 | 3 | 0 | 0 | 14 | 1 | 15 | 93 |
| 10 | 25 | 75 | 92 | 92 | 46 | 48 | 44 | 25 | 3 | 5 | 33 | 9 | 5 | 0 | 0 | 8 | 12 | 20 | 40 |
| 12 | 22 | 80 | 90 | 89 | 51 | 54 | 51 | 29 | 0 | 1 | 30 | 0 | 5 | 0 | 3 | 7 | 10 | 20 | 35 |
| 12 | 54 | 88 | 93 | 93 | 42 | 42 | 42 | 14 | 7 | 4 | 25 | 28 | 5 | 0 | 1 | 9 | 15 | 25 | 38 |
| 12 | 62 | 44 | 79 | 79 | 41 | 44 | 41 | 10 | 3 | 2 | 15 | 20 | 5 | 0 | 0 | 12 | 3 | 15 | 80 |
| 12 | 75 | 67 | 96 | 96 | 65 | 65 | 53 | 22 | 16 | 2 | 40 | 40 | 5 | 0 | 0 | 15 | 0 | 15 | 100 |
| 14 | 19 | 89 | 98 | 96 | 52 | 53 | 50 | 13 | 2 | 5 | 20 | 10 | —— | —— | 1 | 4 | 8 | 13 | 31 |
| 16 | 13 | 65 | 78 | 78 | 46 | 53 | 46 | 8 | 11 | 1 | 20 | 55 | 5 | 0 | 2 | 3 | 10 | 15 | 20 |
| 16 | 16 | 51 | 79 | 79 | 51 | 52 | 49 | 21 | 4 | 0 | 25 | 18 | 10 | 0 | 0 | 11 | 4 | 15 | 73 |
| 16 | 55 | 93 | 94 | 93 | 43 | 43 | 43 | 15 | 3 | 2 | 20 | 15 | 5 | 0 | 0 | 15 | ..... | 15 | 100 |
| 16 | 86 | 51 | 104 | *104 | 59 | 59 | 54 | 22 | 12 | 11 | 45 | 26 | —— | —— | 0 | 8 | 7 | 15 | 53 |
| | | | | | | | | | *Exposed for three hours.* | | | | | | | | | | |
| 23 tubers | 68 | 88 | 95 | 95 | 51 | 52 | 51 | 10 | 9 | 1 | 20 | 45 | 5 | 0 | 0 | 15 | 0 | 15 | 100 |
| 23 " | 69 | 95 | 100 | 100 | 52 | 54 | 52 | 20 | 0 | 0 | 20 | 0 | 0 | 5 | 0 | 15 | 0 | 15 | 100 |
| 23 " | 71 | 52 | 93 | 93 | 48 | 50 | 48 | 12 | 3 | 0 | 15 | 20 | —— | —— | 0 | 12 | 3 | 15 | 80 |
| *Lbs. per cu. ft.* | | | | | | | *Exposed for 24 hours, but double quantity of chemicals were used.* | | | | | | | | | | | | |
| 4 | 78 | 75 | 93 | 89 | 52 | 54 | 50 | 18 | 1 | 1 | 20 | 5 | —— | —— | 0 | 15 | 0 | 15 | 100 |
| 3.7 Dry | 89 | —— | —— | —— | 46 | —— | 45 | 25 | 9 | 6 | 40 | 22.5 | —— | —— | 2 | 5 | 18 | 25 | 20 |
| 3.7 Wet | 89 | —— | —— | —— | 46 | —— | 45 | 47 | 1 | 2 | 50 | 2 | —— | —— | | | | | |

*No doubt there was a supersaturated atmosphere in the fumigator for when it was opened (fumigator was out in the rain) the relative humidity fell to 100 per ct.

TABLE II.— EFFECT OF FORMALDEHYDE GAS ON RHIZOCTONIA; SUMMARY.

| QUANTITY OF POTATOES. | Number of experiments. | TREATED. | | UNTREATED. | |
|---|---|---|---|---|---|
| | | Total number of cultures. | Average percentage showing growth of Rhizoctonia. | Total number of cultures. | Average percentage showing growth of Rhizoctonia. |
| | | | *Per ct.* | | *Per ct.* |
| *Exposed for 24 hours: Standard charge.* | | | | | |
| 23 to 36 tubers | 4 | 60 | 3.3 | 50 | 55 |
| 1.5 lbs. per cu. ft. | 5 | 75 | 7.8 | 75 | 60.8 |
| 2 " " | 5 | 75 | 15.2 | 75 | 67.4 |
| 3 " " | 7 | 105 | 11.4 | 95 | 78.8 |
| 4 " " | 6 | 90 | 13.3 | 90 | 72.1 |
| 5 " " | 1 | 15 | 0 | 15 | 27 |
| 6 " " | 1 | 20 | 0 | 15 | 33 |
| 8 " " | 4 | 95 | 19.3 | 66 | 68.2 |
| 10 " " | 1 | 33 | 9 | 20 | 40 |
| 12 " " | 4 | 110 | 22 | 75 | 63.2 |
| 14 " " | 1 | 20 | 10 | 13 | 31 |
| 16 " " | 4 | 110 | 28.5 | 60 | 54 |
| *Exposed for 3 hours.* | | | | | |
| 23 tubers | 3 | 55 | 21.6 | 45 | 93.3 |
| *Exposed for 24 hours, but double quantity of chemicals.* | | | | | |
| 4 lbs. per cu. ft. | 1 | 20 | 5 | 15 | 100 |
| 3.7 lbs. per cu. ft., dry | 1 | 40 | 22.5 | 25 | 20 |
| 3.7 lbs. per cu. ft., wet | 1 | 50 | 2 | | |

## DISCUSSION OF RESULTS.

The data given in Table I and summarized in Table II, show that the formaldehyde gas treatment is not reliable; that is, it is not efficient in killing Rhizoctonia and some other fungi and bacteria which occur on the surface of the seed potatoes. Humidity and temperature do not appear to be responsible for the irregularities in the efficiency of the treatment. Where several experiments were conducted with equal quantities of tubers, the average results of such experiments show that there is a lesser degree of efficiency when there is a large quantity of tubers in the fumigator. However,

in individual cases where small quantities of tubers are used, the percentage of Rhizoctonia not killed may be almost as high as the average percentage for large quantities of tubers.

TABLE III.— EFFECT OF FORMALDEHYDE AND CORROSIVE SUBLIMATE SOLUTIONS ON RHIZOCTONIA.

| Number of experiment. | Proportions. | Time of immersion. | Temperature C. | Number of cultures on strongly acid agar. | | | | | Agar, one per cent acid. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Sterile. | Showing growth of Rhizoctonia. | Other fungi. | Total. | Percentage showing growth of Rhizoctonia. | Bacterial colonies. | Sterile. |
| | FORMALIN SOLUTION. | | | | | | | | | |
| 1.... | 1-240 | 2 hrs. | 17.5 | 12 | 0 | 3 | 15 | 0 | 15 | 0 |
| 2.... | 1-240 | 2 " | 19 | 73 | 22 | 17 | 112 | 20 | 30 | 0 |
| 3.... | 1-240 | 2 " | 19 | 16 | 10 | 34 | 60 | 17 | 10 | 0 |
| 4.... | 1-240 | 2 " | 19 | 6 | 8 | 16 | 30 | 21 | 10 | 0 |
| 5.... | 1-240 | 2 " | 21 | 23 | 8 | 4 | 35 | 23 | 5 | 0 |
| 6.... | 1-240 | 2 " | 19.5 | 1 | 16 | 8 | 25 | 64 | —— | —— |
| 7.... | 1-240 | 2 " | 22.5 | 6 | 4 | 15 | 25 | 18 | —— | —— |
| 8.... | 1-240 | 2 " | 20 | 9 | 10 | 6 | 25 | 40 | —— | —— |
| Total and average..... | | | 19.6 | 146 | 78 | 103 | 327 | 23.85 | 70 | 0 |
| 1.... | 1-240 | 24 " | 17.5 | 5 | 0 | 0 | 5 | 0 | 5 | 0 |
| 5.... | 1-240 | 24 " | 21 | 18 | 0 | 2 | 20 | 0 | 3 | 2 |
| 6.... | 1-240 | 6.75" | 19.5 | 8 | 0 | 2 | 10 | 0 | 5 | 0 |
| 9.... | 1-60 | 2 " | 21 | 49 | 3 | 8 | 60 | 5 | 7 | 3 |
| 10.... | 1-20 | 2 " | 18 | 15 | 0 | 0 | 15 | 0 | 1 | 4 |
| | MERCURY BICHLORIDE (CORROSIVE SUBLIMATE) SOLUTION. | | | | | | | | | |
| 3.... | 1-1000 | 1.5 " | 19 | 60 | 0 | 0 | 60 | 0 | 0 | 10 |
| 4.... | 1-1000 | 1.5 " | 19 | 40 | 0 | 0 | 40 | 0 | 0 | 10 |
| 9.... | 1-1000 | 1.75" | 21 | 70 | 0 | 0 | 70 | 0 | 0 | 10 |
| 5.... | 1-2000 | 1.5 " | 21 | 40 | 0 | 0 | 40 | 0 | 0 | 5 |
| 6.... | 1-2000 | 1.5 " | 19.5 | 27 | 0 | 0 | 27 | 0 | 2 | 3 |
| 7.... | 1-2000 | 1.5 " | 22.5 | 20 | 0 | 0 | 20 | 0 | —— | —— |
| 8.... | 1-2000 | 1.5 " | 20 | 40 | 0 | 0 | 40 | 0 | —— | —— |
| Total and average..... | | | 20 | 297 | 0 | 0 | 297 | 0 | 2 | 38 |

In Experiment 89 (Table I), there is compared the efficiency of formaldehyde gas on the sclerotia having different moisture content.

In this experiment, the tubers designated as dry were cleaned by dusting off the excess dirt, while the tubers designated as wet were washed with water. Just previous to placing these potatoes in the fumigator, the washed tubers were immersed in distilled water for 45 minutes, and then all excess water was wiped from the surface. The 80 pounds (equal to 3.7 pounds per cubic foot) of potatoes were subjected for 24 hours to the gas evolved from a double quantity of chemicals. Sclerotia of about the same size and texture were used in making the cultures. As there was a slight leakage of the gas from the fumigator these results are only comparative. Of the 40 sclerotia taken from the dry tubers, 22½ per ct. developed Rhizoctonia, while from the 50 moistened sclerotia but 2 per ct. showed growth. This experiment indicates that the state of dessication of the sclerotia has an important bearing on the results of fumigation. One would be led to believe that the humidity of the atmosphere ought to have some effect on the efficiency of this gas, but the data in Table I show no correlation between humidity and efficiency.

The data in Table III show that by the formalin dip method as high as 64 per ct. of the sclerotia may still be alive after the treatment, and an average of 8 tests shows that 24 per ct. of the sclerotia were not killed. A longer period of immersion of the tubers gave more satisfactory results than did a two-hour bath, but the deficiency of the treatment can not be overcome by using a stronger solution.

That the formaldehyde, when used in any form, did not kill resistant spores of the potato bacillus when they were inside the sclerotia or particles of soil, is shown where "agar, one per ct. acid" was used as a culture medium. In fact, so prevalent was this organism that it was impossible to make cultures unless additional acid was added to the medium. That other fungi are not killed by formaldehyde treatments when these organisms are inside of the sclerotia is noted in Table I-III under the heading "other fungi." Most of these fungi were species of Penicillium, but several were uncommon or produced no spores, and no effort was made to identify them.

Where a solution of mercury bichloride of a strength of one part of the salt to 1000 parts of water was used, there was no indication of the growth of Rhizoctonia or of any other fungus or bacterium. Even where half of the above amount of salt was used to a like

amount of water the Rhizoctonia was entirely killed. With a total of 297 cultures the efficiency of mercury bichloride in killing the potato Rhizoctonia was 100 per ct.

The inefficiency of formaldehyde can not be attributed to any single cause, for there are several factors which, when combined, may produce variable results. While making cultures of the sclerotia taken from tubers immersed in formaldehyde solution, it was found that the larger sclerotia were often not moistened throughout. Such sclerotia showed a compact, dry mass of mycelium at the center from which the fungus readily grew. The outer layers, however, were spongy and readily crumbled. In some cases the compact small sclerotia showed the same conditions generally found in the larger ones. The weak penetrative power of formaldehyde may be explained, perhaps, by assuming that the formaldehyde unites chemically with the outer layers of sclerotial tissue forming some substance that retards or inhibits further penetration. This is substantiated by the fact that when tubers are immersed in the ordinary formaldehyde solution for 24 hours the sclerotia are all killed, and it is found that the liquid has penetrated them throughout. Dienes,[18] working on the penetration of formaldehyde gas, has shown that after 14 hours bacteria were killed by the gas penetrating through a porous porcelain plate 20 mm. thick. The structure and composition of the sclerotia, however, is not analogous to that of a porous plate for in the former the compact mass of resting mycelium is more or less in a state of dessication, which affects the rate of penetration of this chemical. Mercury bichloride, unlike the formaldehyde, penetrates all sclerotia, regardless of size or compactness, in $1\frac{1}{2}$ hours. Such sclerotia are all killed, and readily crumble into small pieces when crushed. In the formaldehyde gas treatment, the temperature and humidity, as usually encountered, do not appear to be factors that influence the efficiency. McClintic,[19] in disinfecting passenger cars with formaldehyde gas, states that humidity is an important factor in killing bacteria. He maintains that before starting the fumigation the relative humidity should not be lower than 60-65 per ct. In his earlier work

[18] Dienes, L. Uber Tiefwirkung des Formaldehyds. *Ztschr. Hyg. u. Infectionskrank.* 37:43. 1912.

[19] McClintic, T. B. Pub. Health and Marine Hosp. Ser. U. S. Hyg. Lab. Bul. 27. 1906.

on the treatment of the potato scab, Morse [20] states that a temperature of 60-65 degrees Fahr. is more effective than a lower one, and that in moist air the gas is more efficient. Later [21] he states that a temperature above 80 degrees is most effective. However, under ordinary farm conditions, unless specially equipped, it is almost impossible to obtain a temperature of 80 degrees when it is most desirable to treat tubers. In the preceding bulletin, No. 369, temperature does not prove a factor in determining the cause of the injury to the tubers, but humidity shows some evidence of being a causal agent. The data in Table I of the present bulletin, however, indicate that temperature and humidity are less important in the treatment for Rhizoctonia than is usually believed, for under almost similar conditions widely variable results were obtained. One of the most important factors concerned in the inefficiency is the quantity of tubers in the fumigator. Where several experiments were conducted with the same quantity of tubers the averages show least efficiency where potatoes at the rate of 16 pounds (equal to 167 bushels per 1000 cubic feet) per cubic foot were used. In Bulletin No. 369 it is shown that the factor of adsorption is dependent upon the quantity of tubers in the fumigator. The writer believes that if a sufficient number of experiments were conducted the data would show that there is a gradual decrease in the efficiency of the gas as the quantity of tubers is increased.

The conclusion drawn from laboratory experiments that the formaldehyde gas and liquid treatments are inefficient in killing the Rhizoctonia is partially substantiated by other writers. Rolfs [22] and Güssow [23] conclude, from the results of field experiments, that the mercury bichloride gives better results than the formaldehyde solution. Selby [24] came to an opposite conclusion, namely, that the formalin dip method was better than the corrosive sublimate treatment. However, so far as the control of Rhizoctonia is concerned this conclusion appears unwarranted. The plats in his experiments were very small, mostly on infected soil and the yields irregular. Moreover, the causal relation of Rhizoctonia to rosette is uncertain.

[20] Morse, W. J. Potato Diseases in 1907. Me. Sta. Bul. 149:316. 1907.
[21] Morse, W. J. Blackleg: A Bacterial Disease of Irish Potato. Me. Sta. Bul. 174:325. 1909.
[22] Rolfs, F. M. Colo. Sta. Buls. 70 and 91.
[23] Güssow, H. T. Canada Expt. Farms Rpts. 1912:200.
[24] Selby, A. D. Ohio Sta. Buls. 139 and 145. 1903.

The field experiments of many writers indicate that formaldehyde is as efficient as the mercury bichloride solution in killing potato scab, but there are certain indications that make it appear doubtful if such is actually the case. The difficulty with which formaldehyde penetrates Rhizoctonia sclerotia, and its inability to kill certain other fungi and the potato bacillus suggest that it may, sometimes, be unable to reach and kill the scab organism which, according to Lutman,[25] may be imbedded in the corky tissue of the scab lesions. Also, since adsorption plays such an important role in the formaldehyde gas treatment the efficiency would be least where a large quantity of tubers was fumigated. Unfortunately, the culture method can not be used successfully in determining the efficiency of the treatment on scab. Although it is not difficult to obtain pure cultures of the scab organism it does not grow on culture media readily enough to make this method practicable.

The results of this investigation, considered in connection with those recorded in Bulletin No. 369, seem to warrant the following conclusions: The disinfection of seed potatoes by means of formaldehyde gas is not to be recommended except in cases in which it is impracticable to use either of the liquid treatments. When the treatment is applied for scab alone either corrosive sublimate solution or formaldehyde may be used; but when both Rhizoctonia and scab are involved the corrosive sublimate solution is to be preferred.

[25] Lutman, B. F. The Pathological Anatomy of Potato Scab. *Phytopathology* 3:261. 1913.